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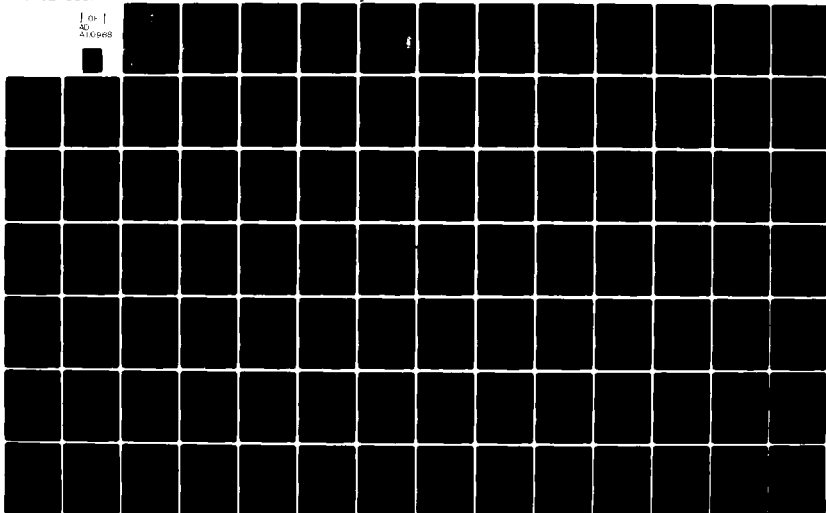
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A REVIEW OF THE USEFULNESS OF  
R & D MANAGEMENT TECHNIQUES

Ricky J. McClary, 2nd Lt, USAF

LSSR 73-81

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER LSSR 73-81	2. GOVT ACCESSION NO. AD-A110	3. RECIPIENT'S CATALOG NUMBER 968
4. TITLE (and Subtitle)  A REVIEW OF THE USEFULNESS OF R & D MANAGEMENT TECHNIQUES		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s)  Ricky J. McClary, Second Lieutenant, USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS  School of Systems and Logistics Air Force Institute of Technology, WPAFB, OH		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Communication and Humanities AFIT/LSH, WPAFB, OH 45433		12. REPORT DATE September 1981
		13. NUMBER OF PAGES 83
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report)  Unclassified
		15a. DECLASSIFICATION/ DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)  23 NOV 1981 Fredric C. Lynch		
18. SUPPLEMENTARY NOTES  APPROVED FOR PUBLIC RELEASE AFR 190-17.  FREDRIC C. LYNCH, Major, USAF Director of Public Affairs Air Force Institute of Technology (ATC) Wright-Patterson AFB, OH 45433		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  R&D Management Techniques      Network Management Project Management Techniques      Cost Schedule Variance Analysis Management Control Systems      Project Scheduling Charts Participative Objective Setting      Work Breakdown Structures		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  Thesis Chairman: Edward J. Dunn, Jr., Lt Col, USAF		

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R & D activities are commonly considered quite different from activities of general management (e.g. production management and administrative management) and thus require different and unique management approaches and techniques. Several management techniques have evolved which seem to be specially suited to R&D planning and controlling. Six techniques chosen for this study are participative management techniques, schedule charts, work breakdown structures, activity networks, generalized networks and cost/schedule variance analysis. This study reviews each of these techniques and reports on empirical data gathered by interview from R&D managers at a large government R&D organization. The data reported includes usage and ratings of effectiveness in R&D planning and controlling.

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LSSR 73-81

A REVIEW OF THE USEFULNESS OF  
R & D MANAGEMENT TECHNIQUES

A Thesis

Presented to the Faculty of the School of Systems and  
Logistics of the Air Force Institute of Technology  
Air University

In Partial Fulfillment of the Requirement for the  
Degree of Master of Science

By

Ricky J. McClary, BS  
2nd Lieutenant, USAF

September 1981

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This thesis, written by

Second Lieutenant, Ricky J. McClary

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS MANAGEMENT

DATE: 30 September 1981

  
COMMITTEE CHAIRMAN

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## CHAPTER I

### INTRODUCTION

#### Background

In order to effectively manage a department from a classical point of view, it is necessary that managers know the objectives of the department; have a means of influencing input; have a means of measuring output; and have a method of comparing measures of output with original objectives, so that corrective actions can be implemented (35:236). The objectives and units of inputs and outputs are sometime not as obvious as the previous statement might have implied. This is especially true in the R&D environment.

In the R&D environment, management is difficult because of several reasons. First, upper level managers sometimes fail to accurately translate their understanding of corporate objectives and goals into the technical environment (30:8). This creates the problem of an ill defined objective and may lead to interesting but undirected experimentation. Second, because most of the scientists, engineers, and technologists in the R&D environment are moderately knowledgable in their field of discipline, they often

feel that they should decide which projects should be undertaken by the organization (30:9). Finally, R&D activities are different when compared to other activities of business such as production and office administration. One difference is that R&D success is more dependent of the individuals involved rather than the equipment used. For example, in a production process a manager could possibly speed up the flow rate of an automated production line if he/she desires more output. It is a different issue to increase the thinking process of an engineer or scientist. Another difference is that production and some administrative processes are more routine than those of R&D. Probably the most important difference is that it is difficult to measure outputs of R&D activities.

Because R&D activities have unique characteristics, appropriate managerial techniques must be used to obtain maximum benefits from limited resources. This need for appropriate techniques was a catalysis in the creation of approaches such as milestone charts, activity networks, and many others. An investigation into the usefulness of these techniques seemed both interesting and significant.

In this study some techniques applicable to R&D management are reviewed in an attempt to identify how often some techniques are used, determine managers familiarity



with the techniques, and determine the usefulness of these techniques.

When probing the issue of usefulness of R&D managerial techniques, several important questions might arise. One such question might be whether the more complex techniques are useful only for organizations with computer support available to them. If no support is available, the techniques may require too much time and effort to serve as a useful managerial tool. A second question might be whether the additional realism derived from using a complex technique is really worth it. For example, consider the results of a specific PERT network analysis first, manually calculated using the original PERT procedures, and second, mechanically computed using Q-GERT, a complex computerized technique. The network completion time was estimated to be 29 weeks (S.D. 8.7) and 32 weeks (S.D. 4.7) using the manual procedure and Q-GERT respectively. Is the difference between the estimates worth the additional expenditure of resources (i.e. time, money, and expertise)? Still another question might be whether a simple heuristic model would be just as accurate as the complex techniques since most of the parameters of both techniques are estimates.

### Terminology

Before discussing the techniques reviewed in this study, key terms need be defined to avoid ambiguity. Basic research refers to research projects which represent original investigation for the advancement of knowledge which has no immediate commercial objective. Applied research involves projects which represent investigation directed at discovering scientific knowledge which has specific commercial objectives (37:4). Development for the purpose of this study is the conversion of scientific knowledge into usable commercial products or processes. These terms are similarly defined in Air Force regulations, but because of the variation, Air Force definitions are also included. Research, according to AFR 80-1, is scientific study and experimentation directed toward increasing knowledge and understanding in the sciences directly related to explicitly stated long-term national security needs. Exploratory Development is a formal effort, ranging from fundamental applied research to sophisticated bread-board experiments, to solve a specific military problem. Advanced Development involves projects that have moved into the development of hardware for experimental or operational test. Engineering Development is the final phase of converting an idea into

a usable commercial product (i.e. a final copy has been developed and is ready for production).

Based on a review of literature, it was decided to focus on six common managerial techniques that are particularly suited for the R&D environment: Participative Objective Setting Techniques (POST), Project Scheduling Charts, Work Breakdown Structures (WBS), Activity Networks, Generalized Activity Networks, and Cost and Schedule Variance Analysis.

POST are techniques whereby the managers, scientists, engineers, and other key personnel jointly identify the program/project objectives, the objective of each functional area, and use the expected results as a means of measuring performance. The participative objective setting approach in effect decentralizes responsibility and authority allowing technical professionals to influence the direction in which the activities of the organization are geared. Formal management by objective systems, participative plans and meetings, and informal participative management are examples of POST.

Work Breakdown Structure display and define the product(s) to be developed or produced and relate the elements of work to be accomplished to each other and to the end product (12:2). The objective of the WBS is to divide

the total program or product into smaller assignable work units. The result is a tree-like diagram (model of the project) of successive levels of project work units as shown in Figure 1.

Project Scheduling Charts are graphical representations of activities and events over a specified time period. In this technique time runs along a horizontal graduated axis and activities are allocated to a number of horizontal bars in some appropriate order. Events are represented by points, sometimes triangles ( $\Delta$ ), on the time scale. The list identifying the horizontal bars and triangles is located along the vertical axis as shown in Figure 2. Performance is measured by comparing actual accomplishments with planned accomplishments over a specified time period.

Activity Networks can be thought of as modified project scheduling charts because in addition to graphically representing activities and events over a specified period of time, activity networks identify all sequences of activities. The network has an arrow for each project activity (31:300). The analysis of activity networks focuses on the most time consuming path (the critical path) through the network as a basis of planning and controlling a project. An example of an activity network is shown in

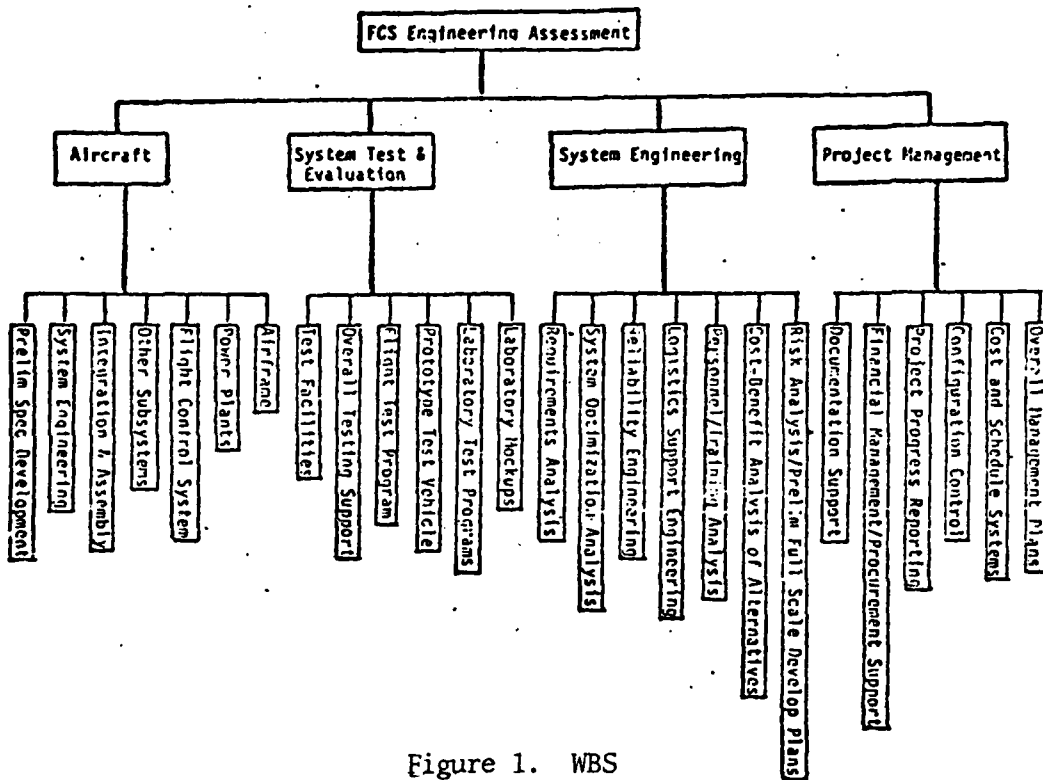


Figure 1. WBS

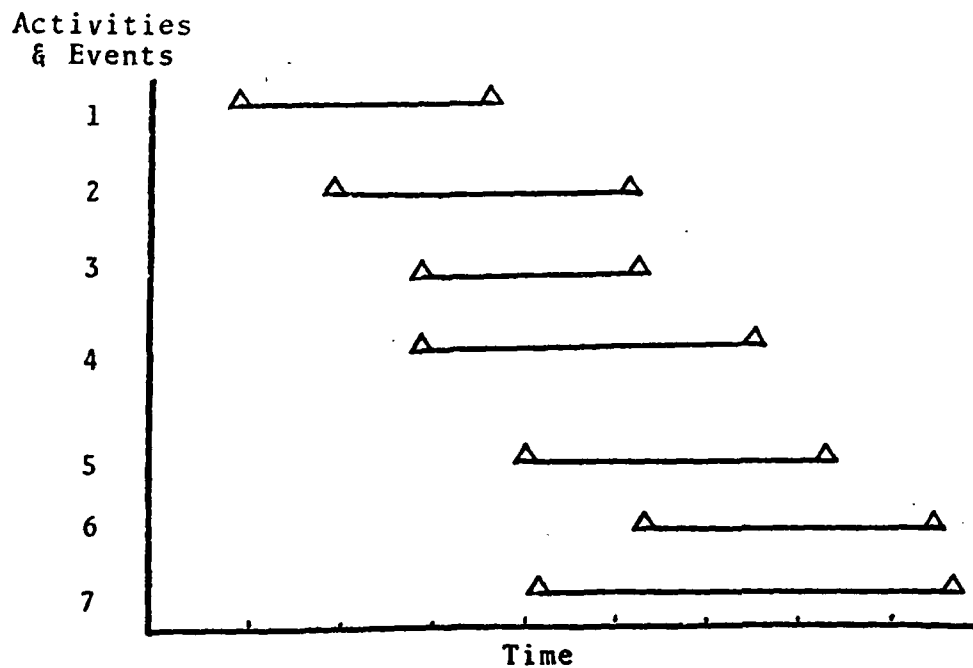


Figure 2. Project Scheduling Chart

Figure 3. Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) are probably the best known activity networks.

In this study all network techniques more complex than PERT/CPM will be considered Generalized Activity Network techniques. Generalized Activity Network techniques allow (i) both deterministic and stochastic branching, (ii) looping, (iii) multiple sink nodes, and (iv) other complications not allowed in PERT/CPM networks (29:53). Events or nodes are considered to have input and output sides which specify how they interrelate to incoming and outgoing actions (branches). An example of Graphical Evaluation and Review Technique (GERT), a Generalized Activity Network, is shown in Figure 4.

Cost and Schedule Variance Analysis is a technique of planning and controlling by comparing planned resource usage and achievements with actual expenditures and accomplishments. When the planned expenditures are plotted against time as shown in Figure 5, any deviations from the budget or schedule are readily recognized. Cost and Schedule Variance Analysis is sometimes used to supplement other techniques since it integrates the cost parameter with the planning and controlling of the performance and schedule parameters for R&D projects.

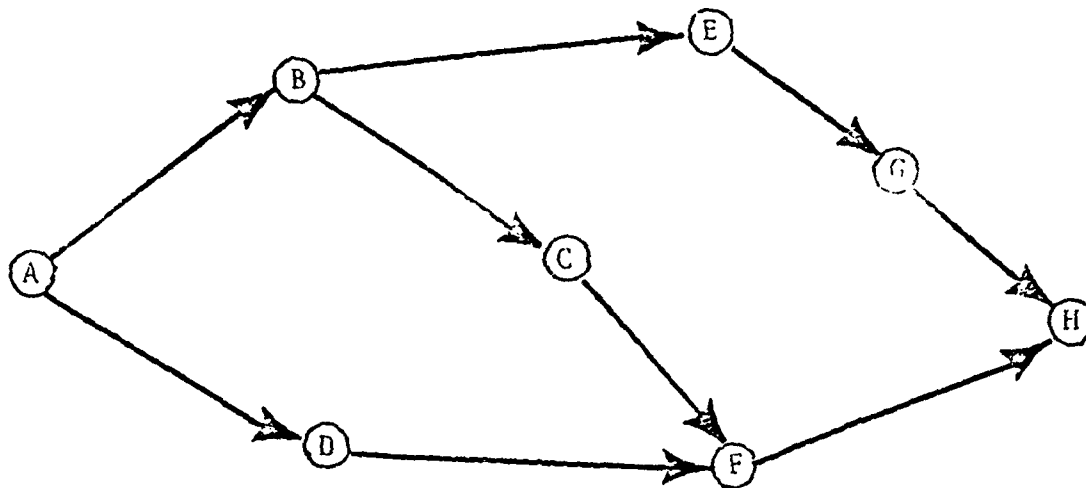


Figure 3. PERT/CPM Activity Network

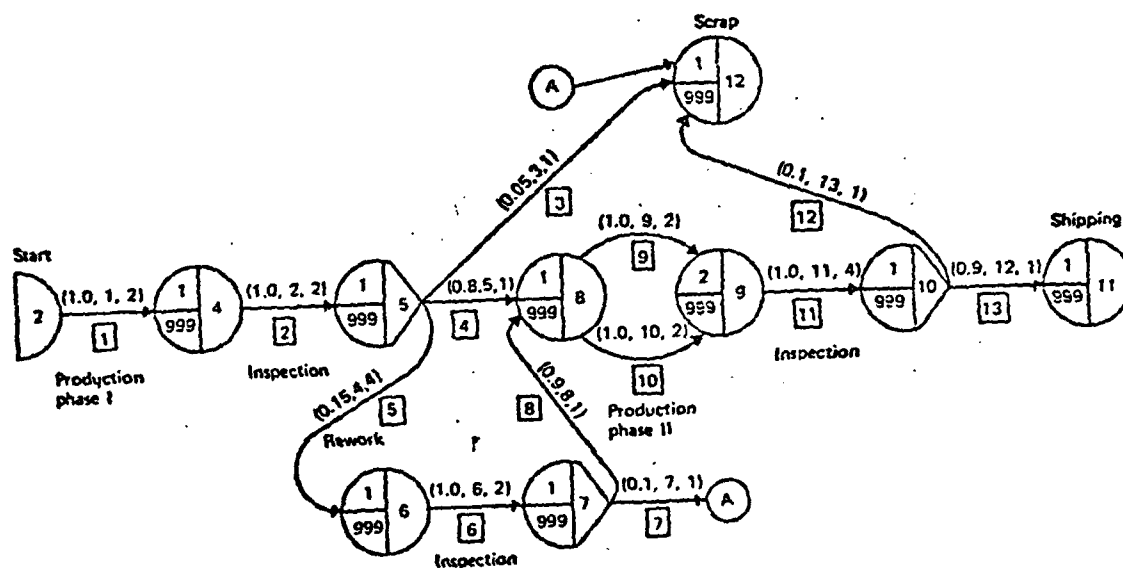


Figure 4. GERT (Generalized Activity Network)  
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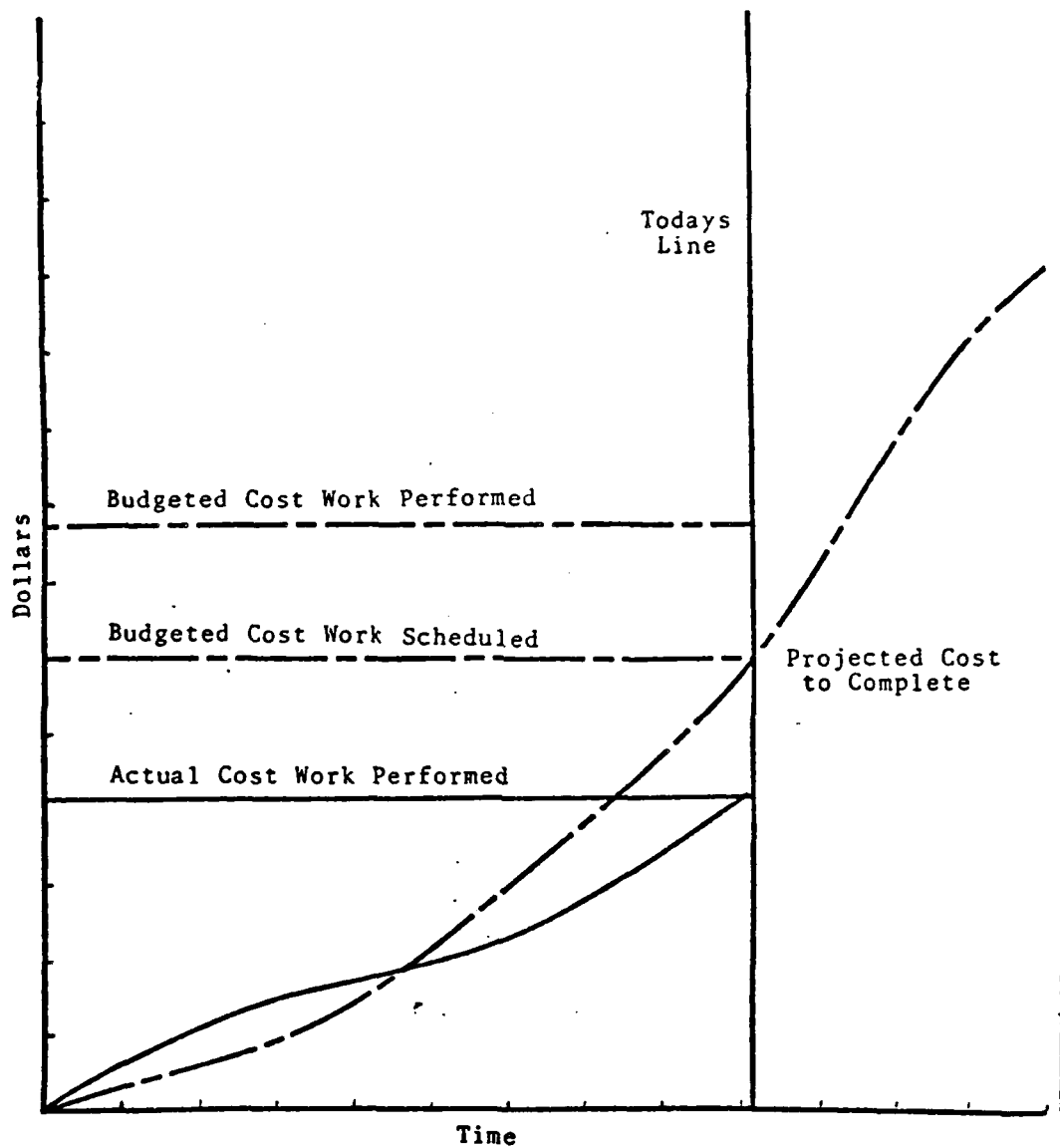


Figure 5. Cost and Schedule Variance Analysis



The objective of this study is to review the use of the R&D techniques that were discussed earlier. More specifically, the overall objectives are to determine how familiar managers of a large government R&D organization are with these techniques; find out how often these techniques are being used; and discover how useful these techniques are in the areas wherein they are being used.

Findings from this study should enhance the understanding of R&D management. Instructors in the management field should benefit from this study since it will help identify prominent techniques for specific areas of R&D management.

#### Scopes and Limitations

Although R&D managers may be concerned with a particular product/process throughout the phases of its life cycle, this study is mostly concerned with the research and design phase. This phase includes basic and applied research in engineering, the sciences, and in the design and development of a prototype and/or process. Topics such as quality control, routine product testing, advertising research, marketing research, and research in the social sciences will not be included in this study. All of the interviews involved employees of Wright-Patterson AFB; therefore, the study is militarily oriented. Because of

the time allowed to complete this study, the sample size and versatility are limited (i.e. the study involved only two product divisions). The techniques analyzed are limited to those introduced. These are not the only managerial techniques used in R&D management, however, the identified techniques appear to be a representative sample capable of accomplishing the described objectives.

#### Methodology

An extensive literature search was conducted to verify that the techniques used in this study are generally accepted as managerial techniques applicable to R&D management. This literature search functioned as the control of the study since this information is mostly theoretical. After the search was completed, a questionnaire was designed to facilitate the interviews. A sample of the questionnaire is shown in the Appendix.

The questionnaire is composed of two scales, a technique familiarity scale and technique usefulness scale. These scales are used to synchronize the responses to several of the questions. A list of the techniques investigated are located on the front page of the questionnaire in the order of increasing complexity excluding the Cost and Schedule Variance Analysis technique which is the only technique discussed that emphasizes the cost parameter.

The questionnaire is also composed of 52 items consisting of 9 demographic items, 6 questions on each technique, and 7 questions that summarize the subjects' responses. Attached to the questionnaire was the recording sheet and a brief description of each technique. The questionnaire served the purpose of regulating the consistency of the interviews.

Upon completion of the questionnaire, organizational charts were obtained for Aeronautical System Division and Air Force Wright Aeronautical Laboratories located here at Wright-Patterson Air Force Base. These charts were used to contact and set up appointments with personnel involved in R&D management. Efforts were directed at interviewing only those persons who had position requiring the use of managerial techniques. After interviewing or contacting the managers listed on the charts (mostly division and branch level persons), other lower level managers were contacted through their bosses. Some of the lower level managers were reached by calling a department and asking for prospects until a contact was made. All interview were conducted on a person to person basis. The subject was given a copy of the questionnaire so that he/she could follow along as the interviewer asked the questions. Re-

sponses were immediately recorded on the sheet provided for that purpose.

The sampling procedure was a stratified plan wherein each strata represented a particular R&D category. Efforts were directed at selecting sample members from each strata in proportion to the cost of that stratum, thus assuring that each strata was weighted in the sample by the cost associated with it. The strata sizes were based on the R&D spending trend for fiscal years 1981, 1982, and 1983. It must be noted that the cost of a project is not always indicative of the number of people involved. However, by breaking the sample into cost strata more data points were gathered in the more costly categories of R&D. This sample design seemed appropriate for the study if the stated objectives were to be achieved.

Sample Demographics. The sample consisted of 60 managers. Of these managers, 36 were employed by the Aeronautical System Division (ASD) and 24 were employed by the Air Force Wright Aeronautical Laboratory (AFWAL). Of the managers from ASD, 25 were military persons and 18 of the managers from AFWAL were civilians. More contacts were made within ASD because it is the largest product division of the Air Force Systems Command (AFSC) and the largest organization here at WPAFB. With an annual budget

of 8 billion dollars, ASD manages the development and acquisition of all aeronautical systems and related equipment for the Air Force. AFWAL links the scientists and engineers in the AFSC laboratories at WPAFB to ASD and other AFSC product divisions, ensuring that the results of laboratory research and emerging new technologies are fully used in the development of aircraft and equipment. AFWAL works directly with AFSC headquarters to plan selected research and engineering development as well as exploratory and advanced development.

Although an attempt was made to incorporate all levels of management, more contacts were made with persons at or below the O-4/GS-14 level. It is believed that this group best represents the part of the population that is responsible for "hands-on" program/project management. A breakdown of the sample by grade is shown in Table 1.

TABLE 1  
Grade

Level of Managment	# Managers			Grade
	Mil	Civ	Total	
Lower	10	3	13	Lt and GS-12
	5	8	13	Cap and GS-13
Middle	10	7	17	Maj and GS-14
Upper	3	8	11	LtC and GS-15
	3	2	5	Col and SEC
			1	Unknown

As shown in Table 1, 43% of the managers were lower level managers; 28% were middle level managers; 27% were upper level managers; and 2% were unknown. A higher percentage of the military persons were in middle and lower level management (32% and 49% respectively) than were their civilian counterparts (25% middle and 39% lower). The difference between grades with respect to familiarity, frequency of use, and usefulness will be presented in Chapter III.

The sample was composed of 31 military persons and 29 civilians. This information is important when discussing the distribution of job experience shown in Table 2. The mode of this distribution was 2.5 years. The mean number of years of job experience (i.e. years in their current jobs) was 3.6 years (S.D. 3.2).

TABLE 2  
Job Experience

Mil	# Managers		Years of Job Experience
	Civ	Total	
15	2	17	1 or less
10	5	15	2 - 3*
4	4	8	3 - 4*
0	7	7	4 - 6*
	5	5	6 - 10*
2	6	8	10 or more

\* - Exclusive

Note that only 33% of the managers had 4 or more years of job experience. Sixty two percent of the civilians had 4 or more years job experience, whereas only 6% of the military managers had the same number of years job experience.

An analysis of the demographic data revealed that the majority of the subjects (managers) worked for ASD; about 72% were ranked 0-4/GS-14 or less; the number of military vs civilian persons was relatively even, however, ASD was 70% military and AFWAL was 75% civilian; and 66% of the sample had 4 or less years experience at their current jobs.

Characteristics of Projects. Variables such as cost; category of R&D; number of people working on the program/project; and number of years the project had been operational are important parameters in identifying a project. Sometimes, however, it is difficult to identify which specific category of R&D a project is in because of transitional periods. For example, during the latter stages of full scale development, the same kinds of activities are going on that characterize the early production phase. Realizing this kind of uncertainty, the subjects were asked to give "best-guess" answers to questions about the characteristics of the program he/she was working on.

Table 3 displays the distribution of managers with

respect to the cost of their program/project(s). Some of the senior managers were responsible for several projects each of which was usually managed by a lower level manager.

TABLE 3  
Project Cost

# Managers	Cost of Project (Mil)
18	3 or less
6	4 - 6
8	7 - 10
7	11 - 25
8	26 - 75
6	76 - 150
7	151 or more

As shown in Table 3 most of the managers were involved with program/project(s) costing less than 10 million dollars. Of the projects costing more than \$10 million, a higher percentage of the managers within a cost group were in the full scale development phase or the early production phase.

Table 4 shows the distribution of managers with respect to category of R&D that the projects were in.

TABLE 4  
Category of R&D

Category of R&D	# Managers
Research	2
Exploratory Development	10
Advanced Development	12
Full Scale Development	31
Early Production	5



Table 5 shows the distribution of managers relative to the number of people here at WPAFB working on the project. The mean number of years that a project was in existence was 5.6 (S.D. 3.2).

TABLE 5  
Project Size

# People Involved	# Managers
10 or less	27
11 - 50	21
50 - 150	10
151 or more	2

After the interviews were completed, the responses were transferred to computer cards for analysis. Cross-tabulation, a program of the statistical package for the Social Sciences (SPSS), was extensively used to aid in analyzing the data. It should be noted that the validity of this study is based not only on the methodology undertaken, but also the truthfulness of the respondents. Efforts were taken to avoid fudging the data to coincide with the theoretically implied applicability and usefulness of the techniques. The theoretical perspectives of the techniques are discussed in the next chapter.

## CHAPTER 11

### THEORETICAL PERSPECTIVE OF TECHNIQUES

#### Introduction

The descriptions in the preceeding chapter of the techniques being investigated were very brief and probably initiated several important questions. Why were these six techniques chosen? How representative are these techniques of all R&D managerial techniques? Are the listed techniques indeed techniques? The purpose of this chapter is to supply answers to the above questions by rendering a more detailed description of the techniques. Each technique will be discussed to disclose strong points, most applicable situations, and if applicable, any mandatory application required by the Air Force.

#### Participative Objective Setting Techniques.

When a program/project operates in an environment of uncertainty, Participative Objective Setting Techniques (POST) are sometimes appropriate for planning and controlling organizational activities (36:11). The idea phase of creating, developing, or perfecting a finished product is an example of an environment of uncertainty. This would especially include the Research and Exploratory Develop-

ment categories of R&D activities wherein it is usual to find a small group of engineers, scientists, and technologist working on a project that is in the conceptual period. During this period there is uncertainty as to the feasibility of creating a final usable product.

As mentioned in Chapter I, POST are techniques whereby the managers, scientists, engineers, and other key personnel jointly identify the program/project objectives, the objective of each functional area, and use the expected results as a means of measuring performance. These techniques provide much of the freedom and flexibility needed by technical workers since they allow the researchers to participate in setting the objectives.

Before discussing any further the details of POST, it is necessary to point out some differences between POST and the other techniques included in this study. First, the term technique is used here in the mildest sense since participative objective setting could also be classified as a "style" of management. A management technique according to John Argenti is "a recognized method of analyzing or solving a recognized type of management problem in a detailed, systematic way [3:5].

Some problems that arise in R&D management are first-time occurrences which makes POST application

especially appropriate. POST is not recognized exclusively by this name because it is a derivative of such techniques or styles as management by objective, participative plans and meetings, and informal participative management.

Second, POST is not a tracking managerial tool in the same sense as the other techniques. For example, the Project Scheduling Charts which will be discussed later are usually based on some unit of time. If the project is behind schedule as far as time is concerned, Project Scheduling Charts will point out this shortcoming. Where as, POST would rely on previously set objectives to determine if a project is behind schedule. POST can be applied when there is not enough information to formulate a Project Scheduling Chart or an Activity Network. However, these tracking systems can be used to compliment POST.

How does POST actually work? These techniques are characterized by three basic steps. First, realistic objectives are periodically established in clear unambiguous terms (19:105). The method of establishing the objectives distinguishes this technique of management from the formal management by objectives system. Program managers, scientists, engineers, and other key persons participate in setting the objective of the organization, thus establishing the direction in which all efforts are geared.

Second, each element (scientists, engineers, etc.) identifies his/her responsibility in realizing the established objectives and sets out to achieve them (2:48). Third, the objectives are reviewed and evaluated by the participants resulting in either continuing the effort, modifying the objectives, or formulating new objectives. This is a critical step in POST since it provides the flexibility required of all R&D techniques. The feedback channel, a common name for this step, accommodates the changing of plans or objectives characterized by an R&D environment and also provides a means of evaluating performance. A diagram of POST is shown in Figure 6. The shaded arrows (▲) illustrate formal changes of the organizational objectives which influences every element and changes the way performance is measured since it is done on a comparative basis. The unshaded arrows (△) represents informal communication channels.

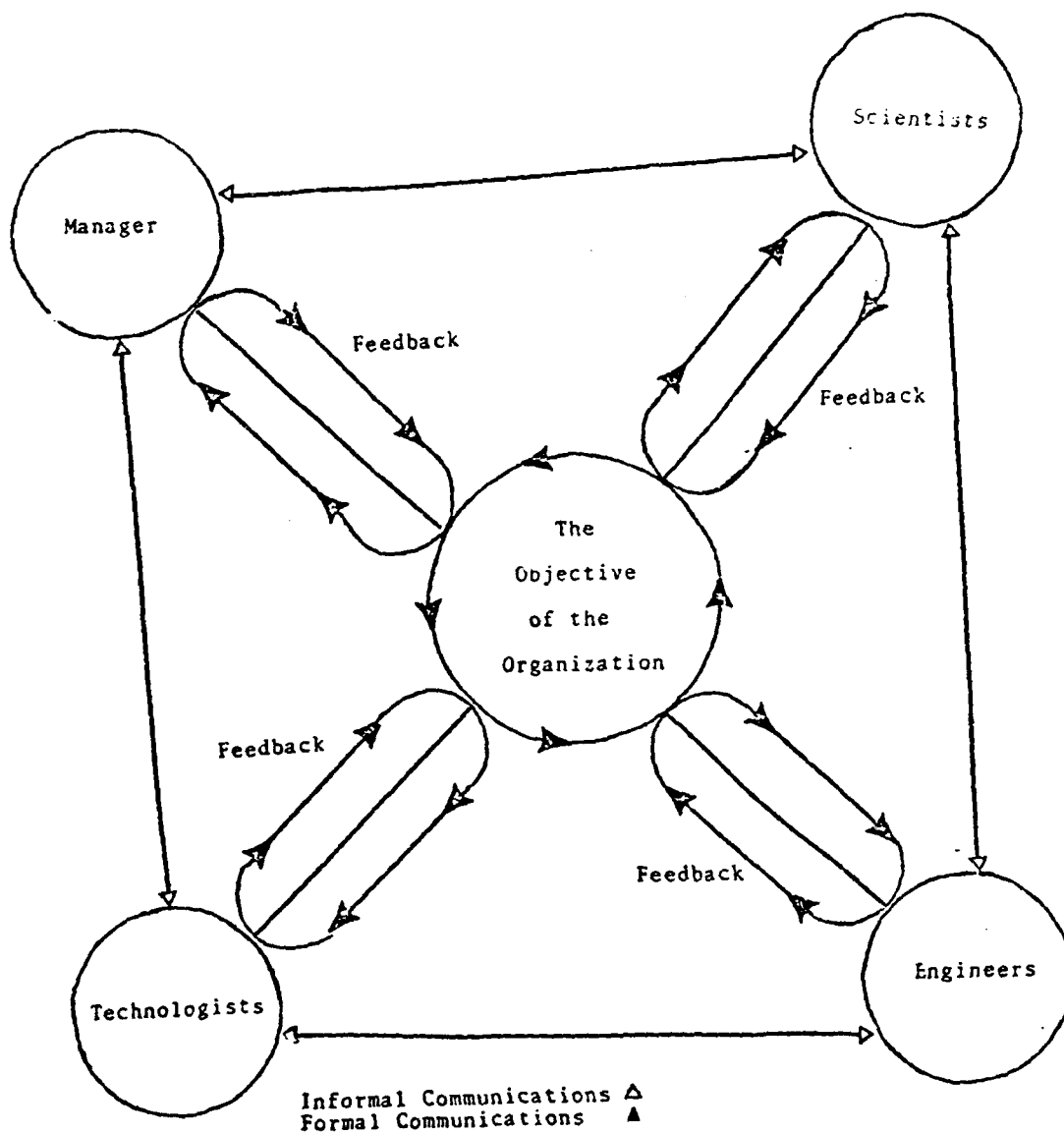


Figure 6. A Conceptualization of Participative Objective Setting Technique. Source (2: Fig. 4-1)

### Work Breakdown Structures

The work breakdown structure (WBS) approach involves breaking a total project up first into major subunits, then breaking the major subunits up into smaller units, and repeated division until the project is broken down into assignable work units. Like POST, WBS are useful techniques as an initial definition of the work necessary to begin implementation of a project. A work breakdown structure is defined in MIL-STD-881A the following way:

A product-oriented family tree composed of hardware, services and data which result from project engineering efforts during the development and production of a defense materiel item, and which completely defines the project/program. A WBS displays the product(s) to be developed or produced and relates the elements of work to be accomplished to each other and to the end product [11:2].

While this definition is system- or hardware-oriented, the WBS concept has a broader historical base, i.e. it has wider applicability than just the world of acquisition management.

The WBS approach provides a logical sequence of breaking down a task, whether it be a feudal tribe operation or a modern program management operation in the manner in which it must actually be performed. It attempts to

model all the key efforts which together constitute the project, thus illustrating the hierarchical relationship among these efforts. However, it should be noted that all relationships are not shown by the WBS model. In the WBS tree, Figure 7, the relationship between system engineering with flight test program, airframe and power plant with all other elements, flight control system with integration and assembly, and so on are not indicated. These relationships could be shown using techniques such as activity networks, but are beyond the scope of a WBS approach.

Establishing the WBS at too low a reporting level can cause distortions and difficulties in accumulating and reporting contract information (12:2). It should be expected that the detail and specificity of a WBS will vary with the size of the project and the phase of R&D wherein it is applied. For example, for a basic research project employing only a few persons with limited chores the WBS would probably include a few generally stated work elements broken down only a couple of levels. As the project progresses so will the complexity of the WBS model. A large complex multi-activity program/project appears much simpler to a manager if he/she is able to focus on individual sub-units of the total program. The WBS approach is a simple



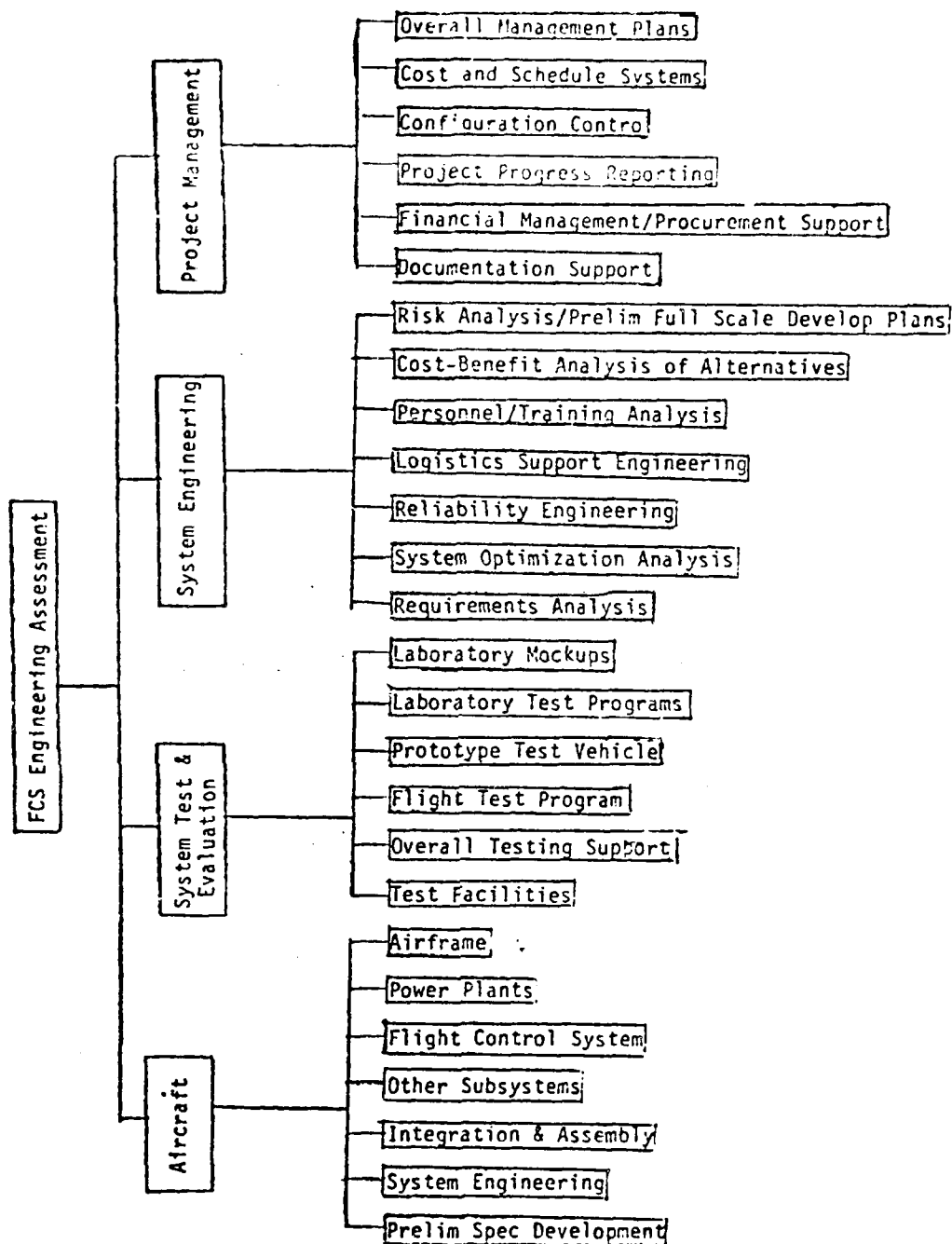


Figure 7. WBS Tree

concept, however, it is powerful in facilitating project definition, initiation of efforts, and control of progress.

The WBS approach is mandatorily applicable to each of the following types of projects:

(1) All defense materiel items (or major modifications) being established as an integral program element of the 5-year defense program (FYDP),

(2) All defense materiel items (or major modifications) being established as a project within an aggregated program element where the project is estimated to exceed \$10 million in RDT&E financing, and

(3) All production follow-on of (1) and (2) above [11:7].

The WBS system provides a basis for drawing networks and for summarizing time status. However, the basis of the system rests on the ability to classify and form hierarchical structures of the project/program wherein it is being applied (14:3).

#### Project Scheduling Charts

Project scheduling charts are graphical representations of events and activities over a specified time period. Like most scheduling techniques the major purpose of project scheduling chart is to manage the time allocated for completion of a program/project. The two best known forms of project scheduling charts are probably the Gantt

chart and milestone chart both of which operate on similar basis (5:251). However, each method of scheduling possesses distinct characteristics.

The Gantt chart as shown in Figure 8 is basically a bar chart or line chart with time graduations shown along the horizontal axis and people, organizations, machines, or tasks shown along the vertical axis (31:299). The bars (or lines) show the time units of work that are scheduled for each activity (person, task, organization, etc.). Milestone charts are somewhat like Gantt charts, but like the name suggests milestone charts emphasize particular events over a specified time period. Milestones are defined as important accomplishments necessary for the success of the project. Notice the similarities between the milestone chart (Figure 9) and the Gantt Chart (Figure 8). In Figure 9 the inverted triangles are objective milestones at which progress is measured. Each time progress is reported, many people must take time to check out and estimate percent completion.

The project scheduling chart shown in Figure 10 is a combination of the Gantt chart and the milestone chart. Project scheduling charts are widely used and popular because they are easily read, thus an excellent form of communication. If project scheduling charts are employed,

# NONREPETITIVE PRODUCTION

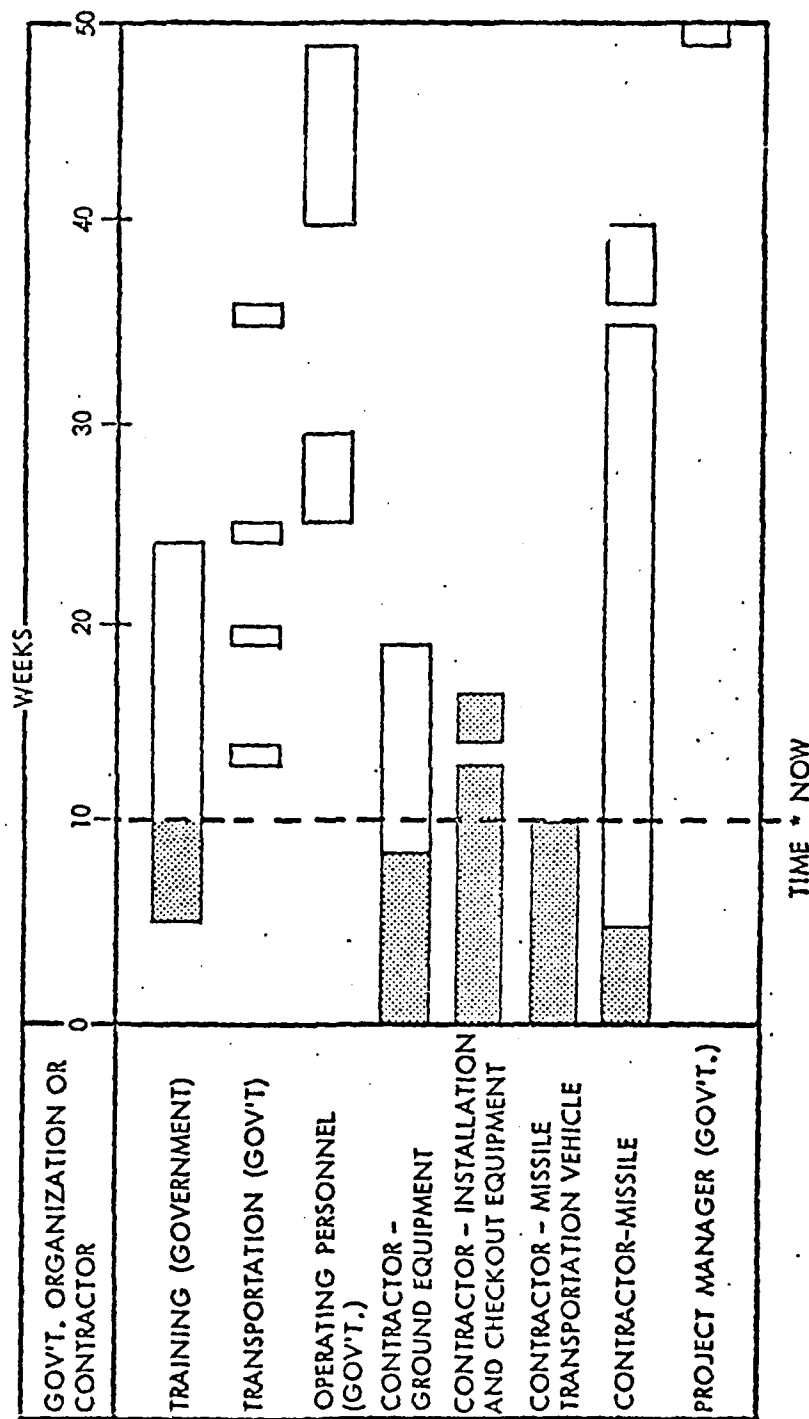


Figure 8. Gantt Chart. Source: AFSCP 800-3, 9 April 1976

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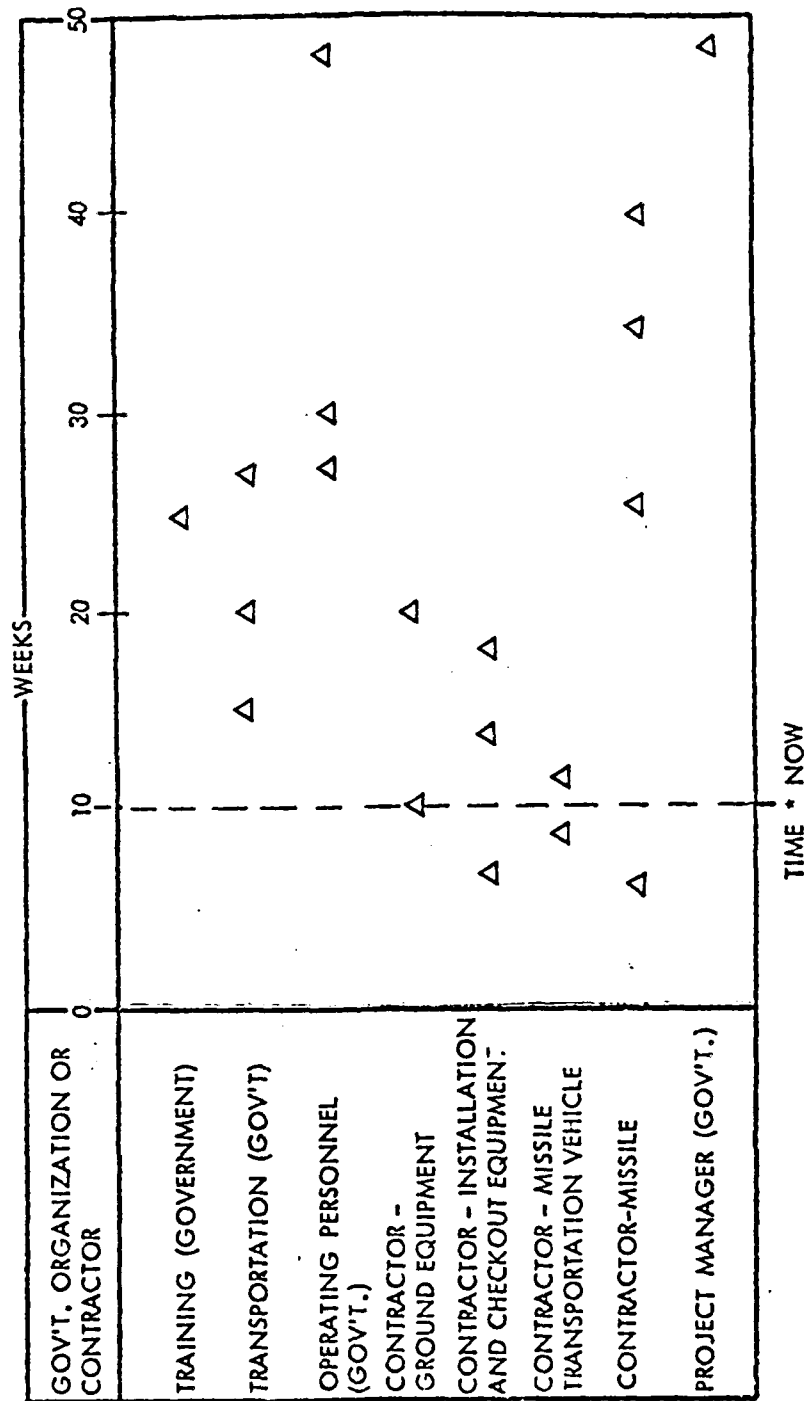


Figure 9. Milestone Chart. Source: AFSCP 800-3, 9 April 1976

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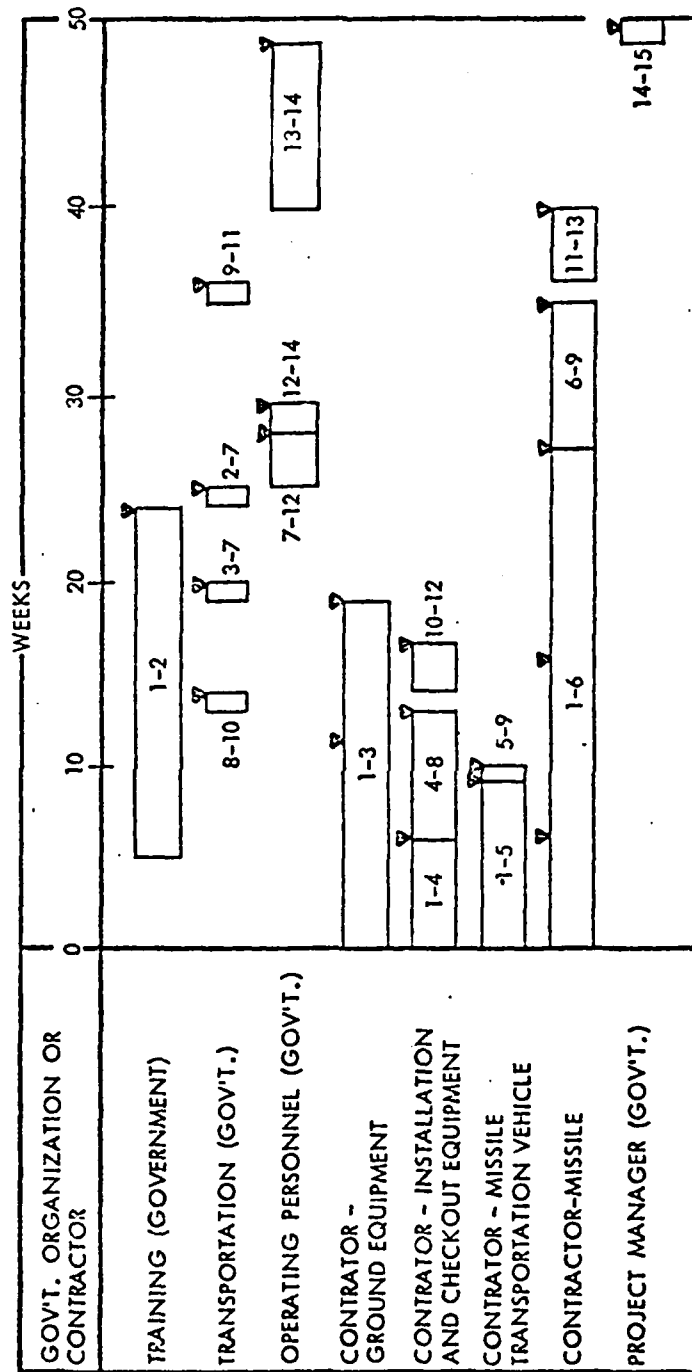


Figure 10. Project Scheduling Chart. Source: AFSCP 800-3, 9 April 1976

the project director can at any time determine whether or not the project is progressing satisfactorily (22:145). However, these charts do have some weaknesses, two of which are inherent. The first weakness is that the chart becomes more useful as the level of detail increases, but this necessitates more line activities resulting in a difficult chart to read. A second weakness is that project scheduling charts do not show the relationship between activities (31:299). Consider the project scheduling chart shown in Figure 10. The relationship between training and transportation, transportation and operating personnel, and so on are not apparent. Although the scheduler can visualize connections, the project scheduling chart cannot record these connections, and the scheduler often may not consider many necessary connections because of the size of the program/project or the degree of detail of the chart.

By balancing the pros and cons of project scheduling charts, the manager can create a very useful tool to track performance (i.e. actual performance can be compared to scheduled performance).

#### Activity Networks

Prior to the advent of activity networks, milestone reporting was the principal tool used to provide information on actual versus scheduled progress in all assigned

areas of work (24:150). If you look closely at activity networks, they are not too different from the old charting techniques. An activity network drawn to time scale is in effect a bar graph which is connected to show interrelationships. Figure 11a is an illustration of an activity network drawn to a time scale. The example is the procedure of a construction company constructing 4 residential units. (31:300) Thus, activity networks can be thought of as modified project scheduling charts that in addition to displaying a graphical representation of activities and events over a specified period of time identify the sequence of occurrence.

The Critical Path Method (CPM) and PERT are two of the best known activity networks and will be used in this study to represent the techniques of this category. The basic difference between the two techniques is the fact that PERT permit explicit treatment of probability in its time estimate where as CPM does not (9:542). This distinction reflects PERT's origin in scheduling advanced development projects that are characterized by uncertainty and CPM's origin in the scheduling of fairly routine activity of plant maintenance. However, for the purpose of this study PERT and CPM will be considered synonymous techniques.



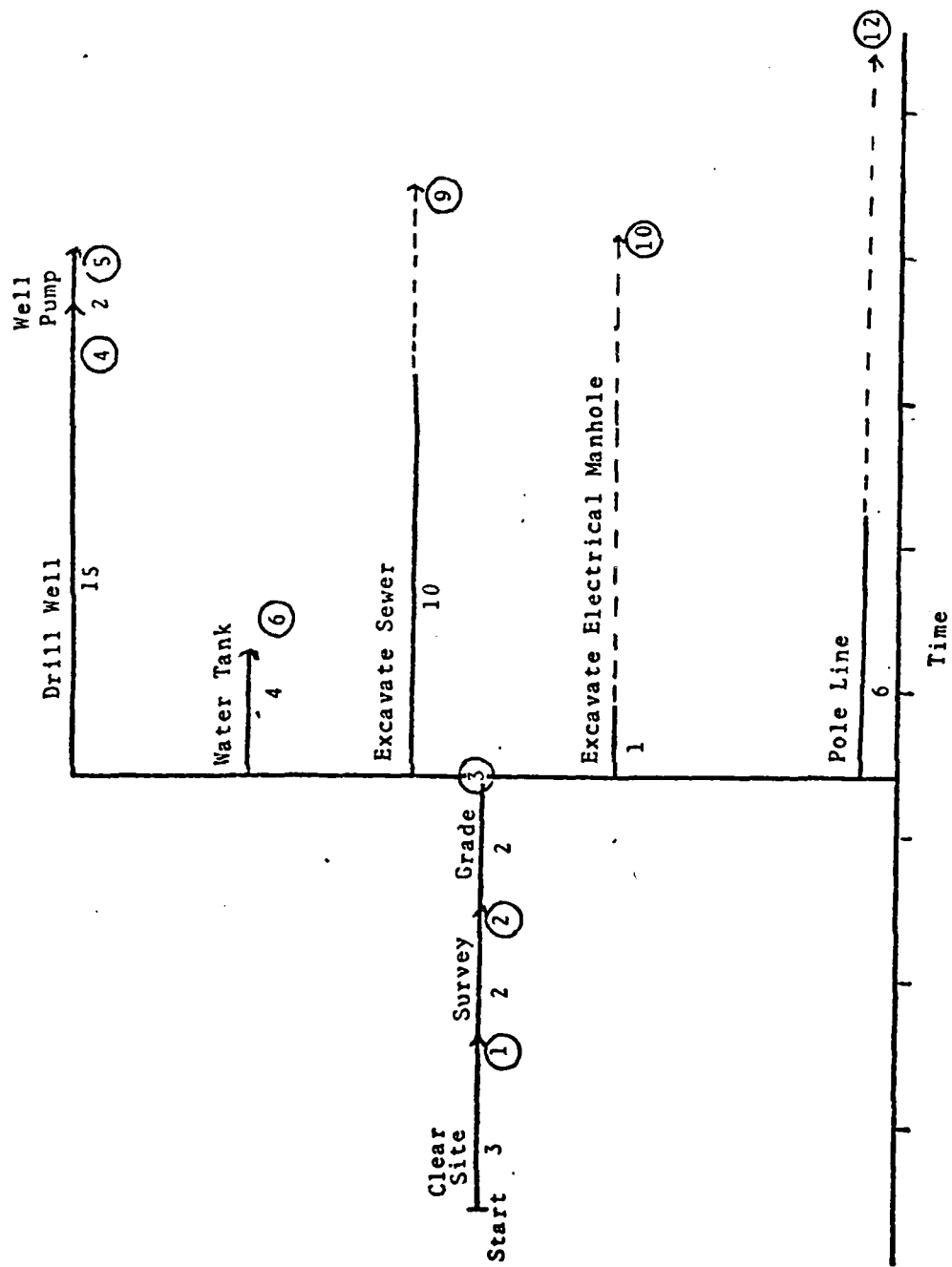


Figure 11a. Project Chart Drawn to Time Scale

Activity networks focus on the most time consuming path through the network as a basis of planning and controlling a project. The following steps are required in developing and solving an activity network (5:34).

1. Identify each activity to be done in the project. Care should be taken to ensure that these activities are at the same level of detail. For example, in constructing a house an activity such as drill the water well would not appear in the same network as connect the water pipes.
2. Determine the sequence of activities and construct a network reflecting the precedence relationships. Activity networks follow an activity on arrow, event on node structure (i.e., arrows ( $\rightarrow$ ) denote activities and nodes ( $\bigcirc$ ) denote events.
3. Ascertain time estimates for each activity. Activity network algorithm requires that three estimated be obtained for each activity:  
  
o = optimistic time. The minimum reasonable period of time in which the activity can be computed.

m = most probable time. The time the activity will be completed under more realistic terms.

p = pessimistic time. The maximum reasonable period of time the activity would take to be completed.

4. Calculate the expected time (ET) for each activity. The formula for this calculation is as follows:

$$ET = \frac{O + 4m + P}{6}$$

This is based upon the beta probability distribution and weights the most likely time (m) four time more than either the optimistic time (o) or the pessimistic time (p). (9:549)

5. Determine the critical path. The critical path is the longest sequence of connected activities through the network and is defined as the path with zero slack time. Slack time may be thought of as the amount of time the start of a given activity may be delayed without delaying the completion of the project (32:357-59).

The most straightforward way to understand activity network is by example. Consider the job listing for com-

pleting a gear box (Figure 11b), and the activity network (Figure 11c) which illustrates the project graphically. By referring to the normal job times (ET) in Figure 11b, it is easy to establish the critical path. At this point the project manager is ready to use the network as a tool for planning and controlling the activities of his/her project.

Construction, study, software, and R&D project managers find activity network to be useful in the majority of cases (27:182). It is not well suited to repetitive production although it may be used to manage the production of the first article. The main advantage of such a technique is that the network approach eliminates fragmentation and brings an integrated methodology into program planning. It indicates every event critical for program performance and shows the activity time that is needed before the next sequential event(s) can take place (25:337). Most planning and control systems also indicates time span and sequence, but they do not draw direct links between the events, the time, and the responsibility for functional performance.

#### Generalized Activity Networks

Realizing that there exist network techniques that are more sophisticated than the activity networks previously discussed necessitates the inclusion of generalized activity networks in this study. Generalized Activity Net-

	Normal			Crash		Cost Slope, \$/week
	Time, Weeks	Float, Weeks	Cost \$	Time, Weeks	Cost, \$	
A Design	2.5	0	450	1.5	700	250
B Drafting	0.8	1.0	140	0.5	200	200
C Check Drawing	0.2	1.0	35	0.1	45	100
D Deliver Special Materials	2.0	0	10	1.0	30	20
E Deliver Bearings, Oil Seals	1.5	3.3	10	1.0	20	10
F Inspect Purchased Parts	0.1	3.3	20	0.05	25	100
G Pattern for Housing	2.3	0	350	1.3	550	200
H Cast Housing	0.2	0	50	0.1	75	250
I Machine Housing	0.4	0	100	0.3	150	500
J Turn Shafts	0.8	1.8	175	0.3	375	400
K Heat Treat Shafts	0.3	1.8	75	0.3	75	
L Machine Gear Blanks	0.8	0.6	175	0.4	325	375
M Cut Gears	1.0	0.6	250	0.5	450	400
N Heat Treat Gears	0.5	0.6	125	0.5	125	
P Assemble	2.0	0	300	1.0	600	300
TOTALS			2265		3745	

Figure 11b. Listing for Completion Gear Box.  
Source: Charles J. Lynch, "How to Schedule a  
Small Design Project," Product Engineering.

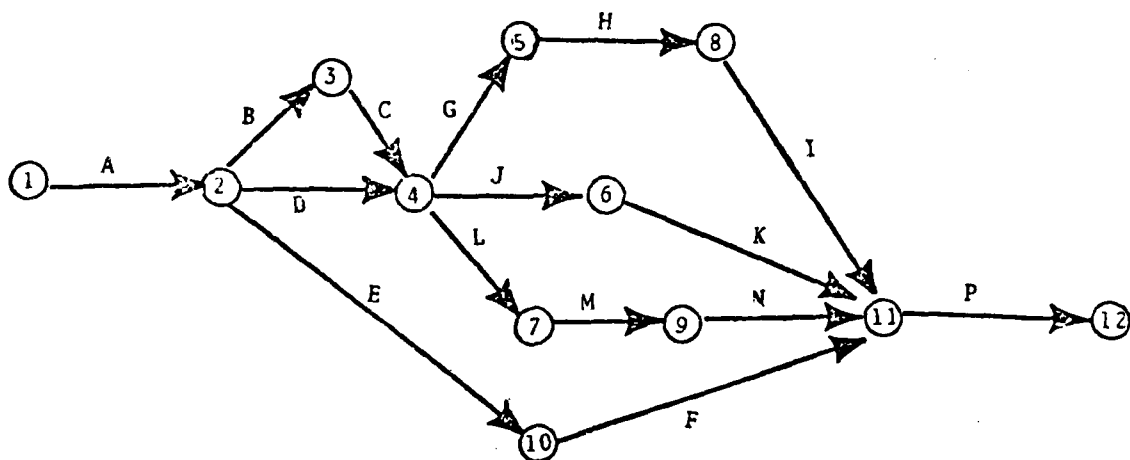


Figure 11c. Diagram for Activity Network  
Source: See Figure 11b

works (GAN's) were introduced in 1964 by Elmaghraby in an effort to cope with the problems of modeling realistic systems. Elmaghraby generalized the structure of activity networks when he defined three types of nodes: AND nodes; Exclusive-OR nodes; and Inclusive-OR nodes.

1. The logical "AND" node ( $\square$ ) is realized when all activities leading into it are realized. Thus the node will be realized at the latest completion time of the activities leading into it.
2. The logical "Inclusive-OR" node ( $\Delta$ ) is realized if any one arc or combination of arcs leading into it is realized. Thus the node will be realized at the earliest completion time of the activities leading into it.
3. The logical "Exclusive-OR" node ( $\bowtie$ ) is realized if one and only one of the activities leading into it is realized (17:323-30).

The following are examples of GAN techniques: Venture Evaluation and Review Technique (VERT), (28:33) Graphical Evaluation and Review Technique (GERT), (30:9) GERT Simulation (GERTS), (17:330) and Q-GERT (32:15). Since GERT is probably the best known of these techniques, it will be used to represent the GANs.

GERT is a generalized network technique allowing both stochastic and deterministic branching, looping, multiple sink nodes, and specified realization times for each event (10:12). These characteristics indeed enhance the opportunity for realism in system modeling; thus, deserve a more detailed description. In GERT networks each activity or branch emanating from a node has associated with it the probability that it will be taken. In the case of deterministic branching, the probability value associated with each activity would be one. As illustrated in the figure below the type of node, deterministic or probabilistic, is identified by the shape of the output side of the node.

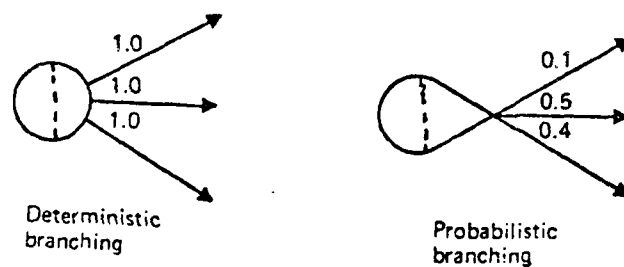


Figure 12. GAN Nodes

GERT networks allow looping; thus, an activity can be repeated and/or terminated at any event that has already been previously realized. Looping might, for example, be included in a network model to depict the situation in which a student repeated a particular phase of a training program. GERT networks also allow multiple sink nodes (terminal events). For example, if the project terminates with the achievement of either of the events, success or failure, then two sink nodes are appropriate. GERT adds to PERT the ability to explicitly deal with uncertainties in flow through the network; thus, establishing itself as a specially useful technique when applied to the planning of R&D projects (6:16).

Consider a space mission involving the rendezvous of two vehicles. In order for the mission to have a chance for success, both vehicles must be successfully launched. Assume further that if both vehicles are successfully launched, at least one of the vehicles must be capable of maneuvering for the mission to be successful. This example is graphically illustrated in Figure 13. Obviously, the example does not supply a complete description; but it illustrates some communication capabilities of GERT.

One of the main advantages of GAN techniques is the ability to simulate project outcome. Since the network can



incorporate probabilistic occurrences both favorable and unfavorable, it is possible to develop a distribution of likely outcomes through repeated runs of the network (15:15). GAN techniques provide a very powerful analytical capability, which may be particularly useful in planning (their forte is not as control systems). They allow management to much more fully assess potential outcomes.

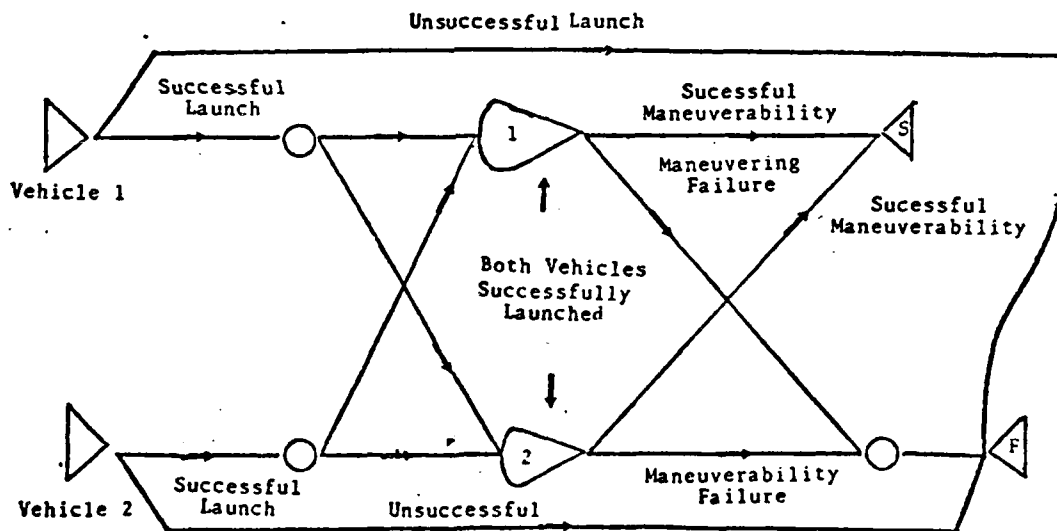


Figure 13. GERT Source: (39: Fig. 8.1)

### Cost and Schedule Variance Analysis

Planning and controlling the project cost are often very important management issues. Some of the techniques already discussed can sometimes be expanded to incorporate project resources expenditures; however, cost and schedule variance analysis has the purpose of simultaneously planning and tracking a project's schedule and cost parameters to determine the progress of the involved activities (4:38). This technique is sometime used to supplement other techniques since it integrates the cost parameter with the planning and controlling of the performance and schedule parameter for R&D projects.

The concepts of this technique are simple but comprehensive. The cost and schedule variance analysis approach starts by the identifying of functional units or work packages. These units which are the basis for establishing a time plan can be identified using project scheduling charts, WBS, ANs, or other such techniques. The second step of this approach is estimating resource expenditure on all work packages relative to time plan (budget). The budget is then used as a control or baseline for determining progress and variance of actual occurrences (20:34). Consider the nonrepetitive production example presented in Figure 14a. By graphing the cumulative cost of each activ-

ity over the specified time period the Budgeted Cost of Work Scheduled (BCWS) is established (Figure 14b). In order to determine the performance in terms of actual progress and cost, it is necessary to derive the Budgeted Cost of Work Performed (BCWP) and the Actual Cost of Work Performed (ACWP). Using these three variable (i.e. BCWS, BCWP, and ACWP) one can calculate the variance in the schedule and the cost which are derived from formulas 2 and 3 respectively.

$$BCWP - BCWS = SV \text{ (schedule variance) F-2}$$

$$BCWP - ACWP = CV \text{ (cost variance) F-3}$$

Once these variances are known managers can sometime make necessary adjustments such that the budgeted schedule and cost are maintained. However, a disadvantage of the Cumulative Performance Chart (Figure 14c) is that it does not emphasize trends toward or away from planned performance. That is, the graphical representation does not indicate which within a work package is causing the increasing/decreasing in cost or time to completion. To answer this question a detailed investigation of each individual activity would have to be undertaken. Another disadvantage is that in the R&D environment, strategies for accomplishing an objective may change. Such changes mean changes to the baseline (20:35).

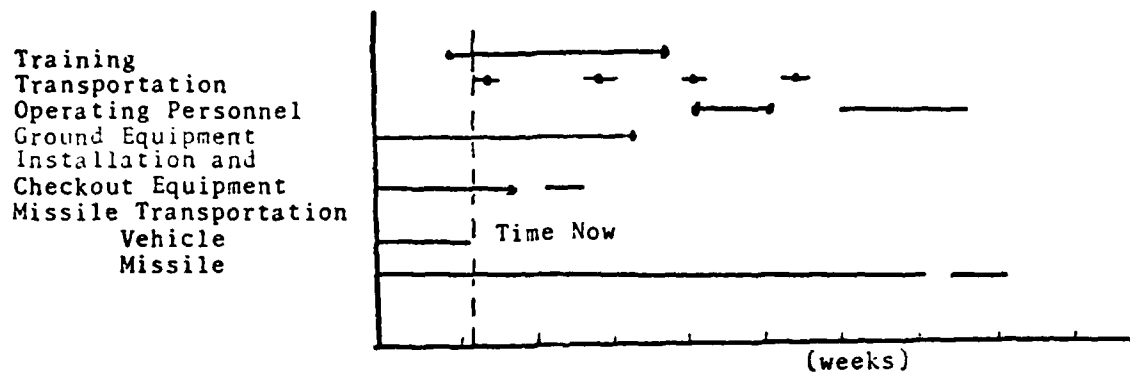


Figure 14a. Project Chart

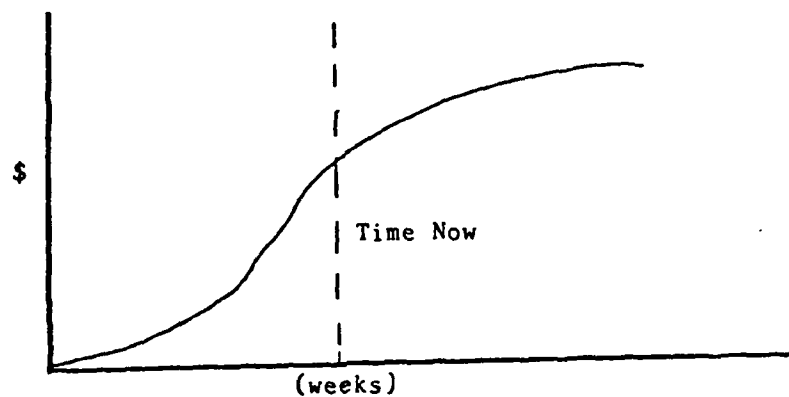


Figure 14b. Budgeted Cost

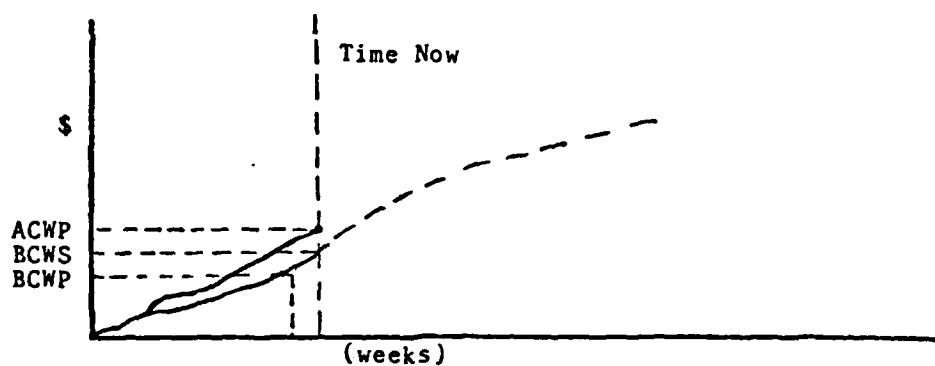


Figure 14c. Cost and Schedule Variance Analysis

The Air Force requirements concerning cost reports are known as the Cost/Schedule Control System Criteria (C/SCSC). AFSC Supplement 1 to AFR 800-6 permits program managers to require the contractor to furnish a monthly Cost Performance Report (CPR) or a monthly Cost/Schedule Status Report (C/SSR) at lower thresholds than specified in AFR 800-6 (1:3). However, either of these reports integrates the contractor's actual with planned cost and schedule performance.

Cost and schedule variance analysis is a RD&E implementation and control technique which jointly considers technical accomplishments, time, schedule, and resource expenditure. It should be noted that this technique is applicable to almost all kinds of projects and can be used at many levels of the program/project.

#### Summary

The six techniques were chosen because of their popularity and flexibility. These techniques are generally accepted (based on the literature review) as being well suited for the R&D environment. All of these techniques are applicable to some aspect of the program/project activities; however, none of these techniques alone would suffice in all possible R&D situations. Therefore, some combination of these techniques must be employed to effec-

tively plan and control project activities.

Theoretically, POST and WBS appear to be more appropriate techniques for planning and controlling project activities during the conceptual phase. Both techniques operate on the principle of decentralization; thus, providing maximum flexibility, responsibility, and creativity to the scientists, engineers, and other key persons. This kind of environment is particularly important during the conceptual period of a project (25:287; 30:8).

Activity networks and project scheduling charts appear to be more applicable to the advance development and/or the early production phase. Activity networks and project scheduling charts operate on the basis of some time unit; therefore, managers must have at least a moderate knowledge of the critical activities required for project completion (22:145; 27:182). GAN and cost and schedule variance analysis could possibly be applicable to activities throughout the entire life cycle of the project. Characteristics such as sink nodes, looping activities, branching, and others give GAN the capability of simulating even the conceptual period of a project. A cost and schedule variance analysis expresses the resource expenditure of a project and is thus applicable to most situations (15:14; 1:3).

One major aspect of R&D management is the orchestrating of these techniques so that the project(s) operates efficiently and effectively. Although successful project management is much more than choosing managerial techniques, the project manager's planning and evaluating process is considerably more effective if it uses the right mix of techniques. And while the right set of techniques certainly varies from project to project, it also does so within the life cycle of any given project (27:182).

## CHAPTER III

### ANALYSIS OF DATA

#### Introduction

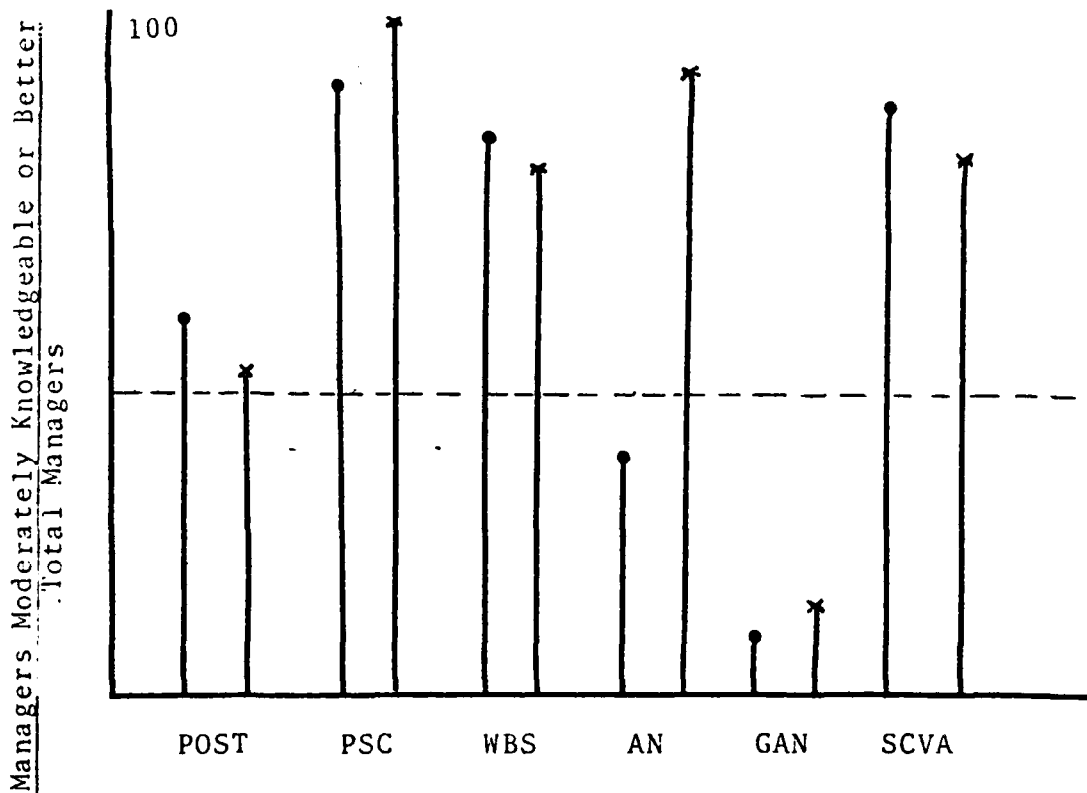
The purpose of this chapter is to present the findings of the study. In this chapter the following issues are discussed: how familiar the managers were with the techniques; how often were the techniques being used; how useful were these techniques thought to be in the areas where in they were being used; the usefulness of the various techniques relative to the availability of computer support; and the primary technique used by the managers interviewed.

#### Familiarity with Techniques

Only a few (10%-15%) of the managers had to refer to the brief descriptions of the techniques attached to the questions to confirm their understanding of the techniques. As shown in Figure 15, 50% or more of the managers of both organizations were at least moderately knowledgeable about all the techniques excluding the network techniques. Only 42% of the managers of AFWAL were moderately familiar or better with the activity networks. This finding might be indicative of the difference between



lab activities and development activities. Managers of neither organizations were familiar with GAN to a significant degree. Managers of both ASD and AFWAL were more familiar with project scheduling charts than any of the other techniques. Managers of ASD and AFWAL were about equally familiar with POST, WBS, and CSVA.

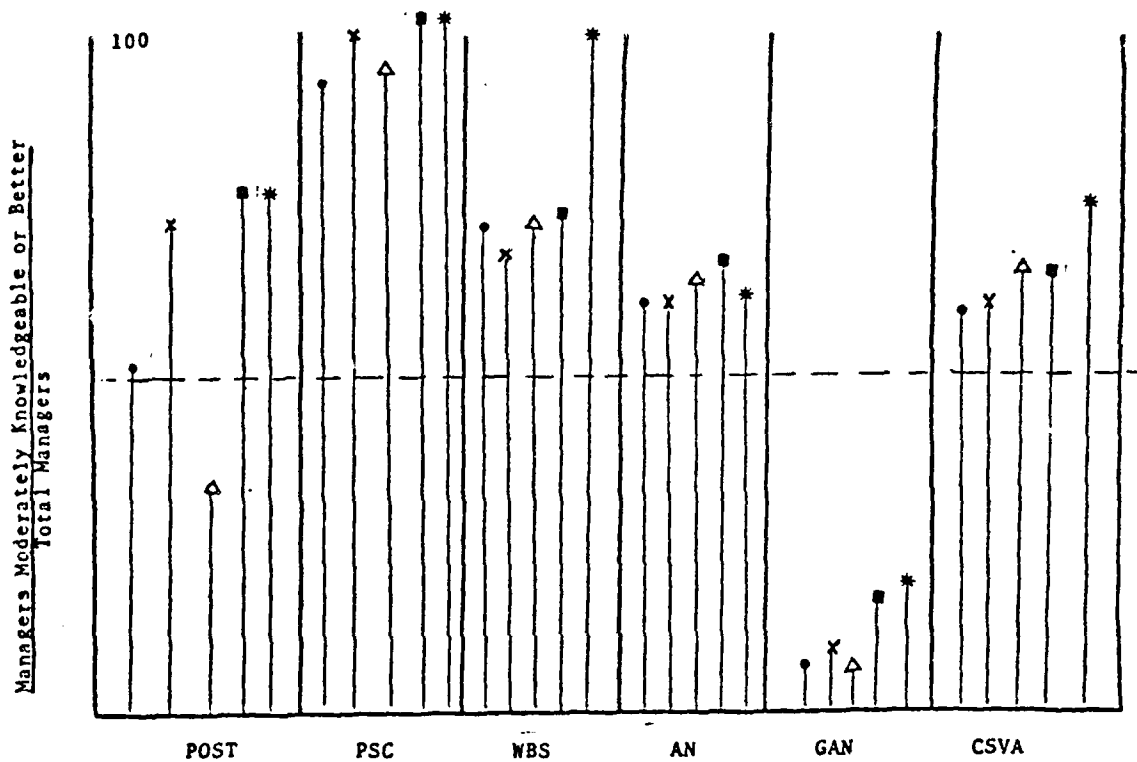


Code	Organization	Total
•	AFWAL	24
x	ASD	36

Figure 15. Familiarity by Organization

Figure 16 is a graphical representation of the managers' familiarity, with the techniques by grade. Most of the managers were at least moderately familiar with the techniques that were investigated. GAN were less common than any of the others over the entire range of grades. It appears that increasing rank was associated with increasing familiarity. The familiarity with POST was lowest in the Major and GS-14 group (only 35% of this grade were moderately familiar or better with the technique; 53% of the Lt/GS-12 were at least moderately familiar with the technique; and the other groups were relatively equal at about 80%). The Col/SES group was much more familiar with WBS than the other groups. All of the Col/SES were at least moderately familiar with WBS. The managers of all grades were most familiar with PSC.

As shown in Figure 17, most of the managers (military and civilian) were at least moderately knowledgeable about the techniques, excluding GAN with which the managers were hardly familiar. In most cases the two groups were relatively equal in familiarity with the techniques. Civilian managers, however, were considerably more familiar with POST and CSVA than were their military counterparts.



Code	Grade	Total
•	Lt/GS-12	13
X	Capt/GS-13	13
△	Maj/GS-14	17
◻	LtC/GS-15	11
*	Col/SES	5

Figure 16. Familiarity by Grade

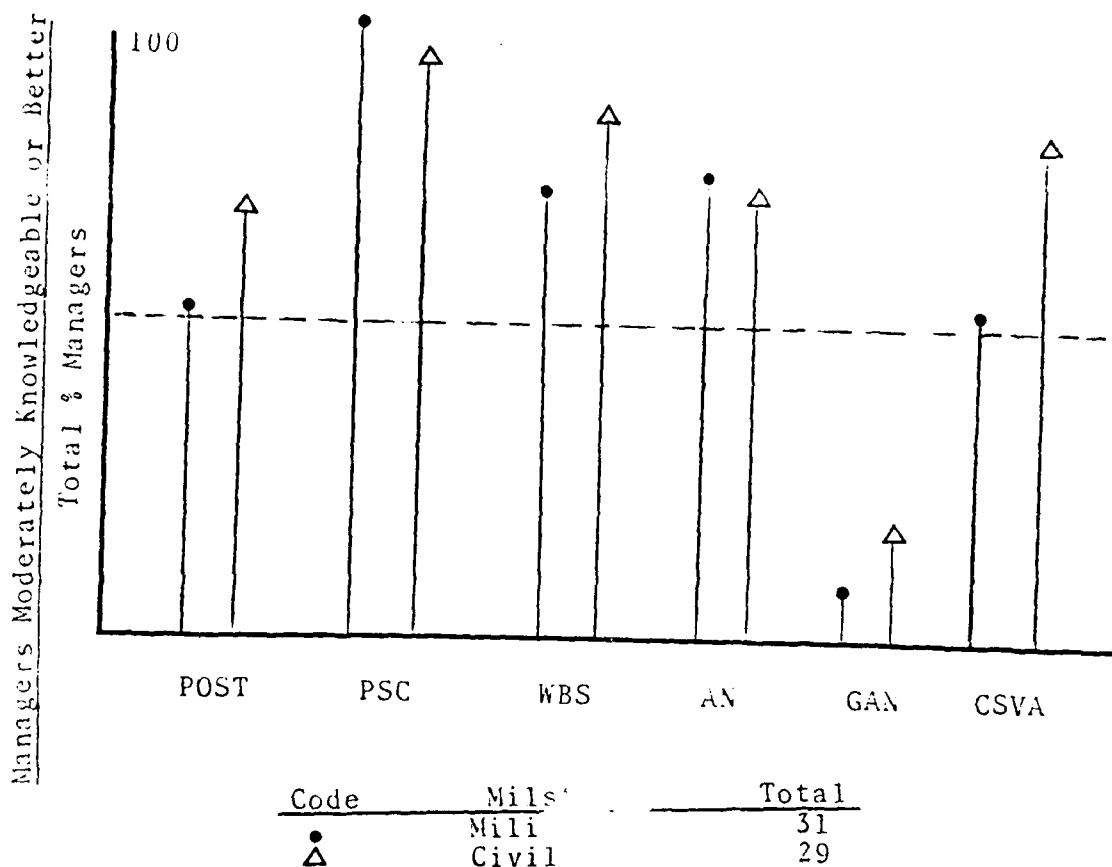


Figure 17. Familiarity by Military Status

#### Frequency of Use

As shown in Table 6, project scheduling charts were used by more managers for both planning and controlling than any of the other techniques. Only 1 of the 60 managers indicated that PSC were never used. Next to PSC, WBS were used by more managers than were the other techniques. POST followed WBS in the number of managers that use it. CSVA, AN, and GAN ranked fourth, fifth and sixth respectively in the number of managers using them.

TABLE 6  
Frequency of Use

Technique		Frequency of Use			
POST		Never	Occasionally	Often	Always
	Plan	17	13	19	11
	Control	17	17	17	9
PSC					
	Plan	1	10	19	30
	Control	1	11	25	23
WBS					
	Plan	11	24	19	6
	Control	10	27	16	7
AN					
	Plan	33	18	7	2
	Control	37	14	6	3
GAN					
	Plan	55	5	0	0
	Control	56	4	0	0
CSVA					
	Plan	22	15	16	7
	Control	18	18	14	10

Only two networks were used by less than 50% of the managers. Approximately 58% of the managers never used AN and almost 93% never used GAN. The rankings were the same for both the planning and controlling of project activities. Note that all of the techniques were used to some degree.

Twenty five percent of the managers indicated that they were using techniques that were not included in the study. A list of the other techniques included the following: Heuristic (8), Plans & Meetings, Road Maps (2), Management Control System, Management Assessment Report, Formal Management by Objective, and Versions of CSVA (Cost Performance Report and Cost/Schedule Control System Criteria). The frequency of occurrence is indicated by the number in parentheses.

### Usefulness of Techniques

The degree of usefulness appears to vary directly with the frequency of use (i.e. a technique that was used frequently got a higher usefulness rating than a technique that was not used quite as often). As shown in Table 7a, project scheduling charts and POST were the only techniques that had 50% or more of the managers using them to indicate that these techniques were better than average planning techniques. The usefulness of WBS, CSVA, and AN were ranked relatively equal as planning techniques. Table 7b shows that project scheduling charts and CSVA were the two techniques which received similar high ratings as control techniques. The usefulness of POST, WBS and AN were ranked relatively equal as control techniques. GAN were rated last in both planning and controlling categories.

It must be noted that the ranking process mentioned above did not take into account the number of people actually using the techniques or did it weigh various usefulness rating differently. The ranking process shown in Table 8a attempts to incorporate these two factors. The major differences in the results of this measure of usefulness are that (i) PSC is ranked much higher than POST as a planning technique when the number of managers using the techniques are considered, and (ii) AN were not ranked as

TABLE 7a  
Usefulness for Planning

Plan	POST	PSC	WBS	AN	GAN	CSVA
No Use	--	-	.041	.037	-	--
Some Use	.116	.068	.204	.259	.600	.132
Same As	.116	.237	.286	.333	.200	.395
More Useful	.419	.254	.204	.259	.200	.184
Very Useful	.279	.407	.245	.111	-	.289
Best	.070	.034	.020	-	-	--

TABLE 7b  
Usefulness for Controlling

Control	POST	PSC	WBS	AN	GAN	CSVA
No Use	--	.016	.060	.043	-	--
Some Use	.186	.102	.180	.261	.250	.143
Same As	.349	.254	.340	.304	.500	.238
More Useful	.233	.288	.180	.304	.250	.238
Very Useful	.209	.322	.220	.087	-	.333
Best	.023	.017	.020	-	-	.048

TABLE 8a  
Usefulness Ranking

Technique Used	Total # Using Mgrs		Ranking	
	Plan	Control	Plan	Control
POST	43	43	8.95	5.51
PSC	59	59	13.0	8.78
WBS	49	50	7.95	7.75
AN	27	23	3.60	3.23
GAN	5	4	0.43	0.40
CSVA	38	42	6.65	8.07

close to the other techniques in either planning or controlling when the number of users and the usefulness ratings were considered.

An investigation into the usefulness of the techniques with respect to the availability of computer support indicated that no relationship existed in most of the cases.

Each ranking index is the product of the "usefulness" 1, 2, 3, 4, 5, 6, the "frequency of usefulness" - 2, 3, 4, and percent in each cell. For example, consider the calculation of the POST plan index. Table 8b shows the distribution of the management responses and the procedure for calculating ranking indices.

TABLE 8b  
POST Planning Ranking

	(2) same use	(3) same as others	(4) more useful	(5) very useful	(6) best
(2) Occasional	5	4	3	1	0
(3) Often	0	0	11	7	1
(4) Always	0	1	4	4	2
<hr/>					
(2)(2)(5/60) = .333	(3)(2)(0/60) = 0	(4)(2)(0/60) = 0			
(2)(3)(4/60) = .400	(3)(3)(0/60) = 0	(4)(3)(1/60) = .200			
(2)(4)(3/60) = .400	(3)(4)(11/60) = 2.20	(4)(4)(4/60) = 1.07			
(2)(5)(1/60) = .167	(3)(5)(7/60) = 1.75	(4)(5)(4/60) = 1.33			
(2)(6)(0/60) = 0	(3)(6)(1/60) = 0.30	(4)(6)(2/60) = 0.80			
	<u>1.30</u>	<u>4.25</u>	<u>3.40</u>		
Total = 8.95					

#### Primary Technique(s)

The managers interviewed were asked to identify the primary technique or combination of techniques that they were using for planning and controlling purposes. Table 9 shows their responses.



TABLE 9  
Primary Techniques

PLANNING		CONTROLLING	
Frequency	Technique(s)	Frequency	Technique(s)
26	PSC	21	PSC
18	POST	16	CSVA
4	WBS & PSC	11	POST
3	AN	3	WBS & PSC
2	CSVA	2	WBS
1	POST & WBS	1	WBS & CSVA
1	POST & PSC	1	PSC, WBS, CSVA
1	PSC, WBS, CSVA	1	AN & PSC
1	WBS	2	AN & CSVA
1	WBS, AN, CSVA	1	GAN
2	No Response	1	CSVA & PSC
		1	No Response

As shown in Table 9, 53% of the managers were using project scheduling charts alone or with other techniques as a primary means of planning their project activities. Of the managers, 33% were using POST or some combination including POST as a primary technique for planning their project activities. WBS, CSVA, AN and GAN were seldom used as primary planning techniques.

Of the managers, 45% used PSC or some combination including PSC as a primary control technique; 35% used CSVA alone or with other techniques as a primary means of controlling their project activities. About 18% used POST; the remaining techniques were seldom used.

The managers were also asked to identify those techniques that should be their primary means of planning and controlling. These responses shown in Table 9. This occurrence indicated that the managers felt that they were using the most appropriate technique.

## CHAPTER IV

### DISCUSSION AND CONCLUSIONS

#### Summary

Because the activities of research and development management are different from those of management in general, so must the techniques that are used to plan and control these activities be different. Six Techniques considered to be particularly suited for R&D management were investigated to determine how familiar managers were with these techniques; how often they used these techniques; and how useful were these techniques in the areas wherein they were being applied. The following techniques were investigated in this study: Participative Objective Setting Techniques, Project Scheduling Charts, Work Break-down Structures, Activity Networks, Generalized Activity Networks, and Cost and Schedule Variance Analysis. The complexity of these techniques range from the simple bar graph of the project scheduling charts to the computerized probabilistic network system of the generalized activity networks.

To accomplish the objectives of determining the usefulness, familiarity, and frequency of use, 60 managers at a large government R&D installation were interviewed. More

specifically, the sample consisted of 36 managers in the development area and 24 managers concerned with laboratory activities.

The managers were most familiar with the project scheduling charts and least familiar with the generalized activity networks. Managers were about equally familiar with the remaining four techniques. Project Scheduling Charts were also used more frequently than the other techniques and were rated the most useful of the six techniques for both planning and controlling project activities. Generalized activity networks were used less frequently than the others and were rated the least useful of the six techniques for both planning and controlling purposes. PSC followed POST in rank as a planning technique when frequency of use and usefulness rating were considered. Cost and schedule variance analysis followed PSC in rank as a control technique. Activity networks were ranked next to last in all cases.

There was no significant relationship between the usefulness of the techniques and the availability of computer support. The techniques that usually make use of the computer were the lowest rated in usefulness, frequency of use, and managers' familiarity with them.

Although WBS were used rather frequently, only a small percentage of the managers considered it a primary planning or control technique. More managers identified PSC as their primary planning and control technique than any of the others. POST and CSVA were next to PSC in planning and controlling respectively.

### Conclusions

This study clearly is not the "absolute statement" about R&D management techniques since this study is based on only 60 interviews at a single government R&D installation. However, this study should serve the purpose of furnishing some insight as to which techniques are useful in R&D management.

At the government installation studied the simplest technique, project scheduling charts, was found to be more useful than the more complex techniques. It appears that as the complexity of the techniques increased their usefulness decreased. The high rating of POST as a planning technique indicated a decentralized planning process which incorporated the expertise of key employees. It appears that the cost parameter is very important when attempting to control project activities. This is attested to by the high rating of CSVA as a control technique. The conven-

ience of computer support was insignificant in altering the way managers do their jobs.

#### Recommendations

A study that incorporated more R&D managers from both the government and industry environments could be undertaken in order to be able to draw more general conclusions about R&D management techniques. Also, it would be interesting to investigate the relationship between categories of R&D (i.e. basic reseach, applied research, and developmental research) and the technique used.

Appendix

Sample Interview Formats

### Participative Objective Setting Technique

When a program or project operates in an environment of uncertainty, Participative Objective Setting Techniques are sometimes appropriate for planning and controlling program/project activities. The term technique is used here in the mildest sense. Since participative objective setting could also be classified as a "style".

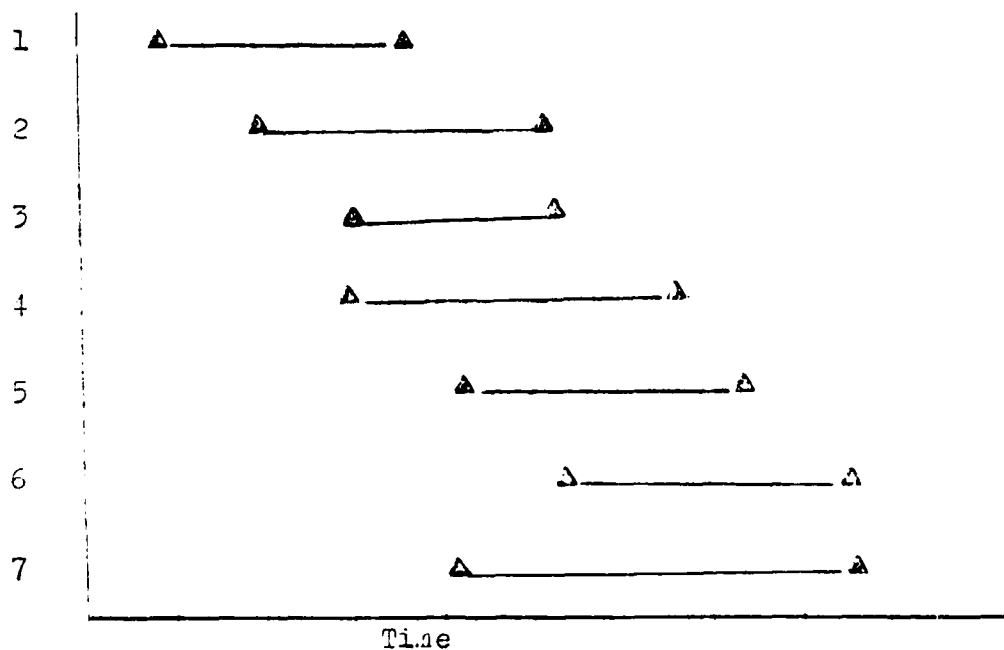
Participative Objective Setting Techniques are techniques whereby the managers, scientists, engineers, and other key personnel jointly identify the program/project objectives, the objective of each functional area, and use the expected results as a means of measuring performance. The participative objective setting approach in effect decentralizes responsibility and authority allowing technical professionals to influence the direction in which the activities of the organization are geared. Formal management by objective systems, participative plans and meetings, and informal participative management are examples of Participative Objective Setting Techniques.



### Project Scheduling Charts.

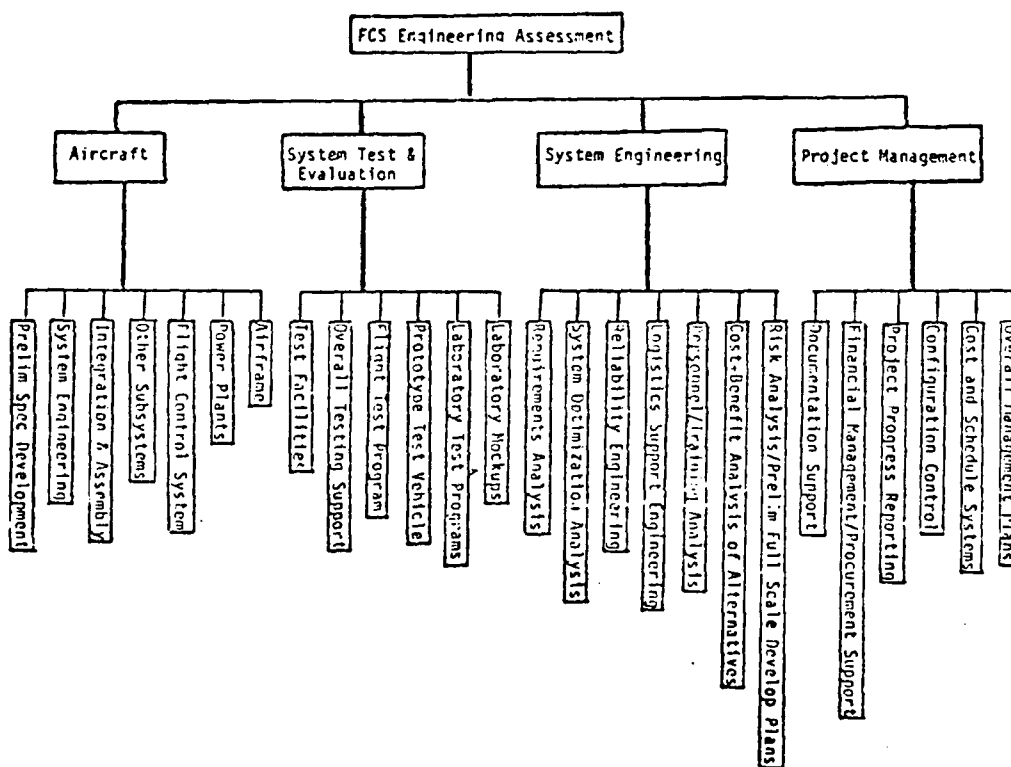
Project Scheduling Charts are graphical representations of activities and events over a specified time period. In this technique time runs along a horizontal graduated axis and activities are allocated to a number of horizontal bars in some appropriate order. Events are represented by points, sometimes triangles ( ), on the time scale. The list of activities and events identifying horizontal bars and triangles respectively is along the vertical axis as shown in the figure below. Performance is measured by comparing actual accomplishments with planned accomplishments over a specified time period.

Activities  
&  
Events



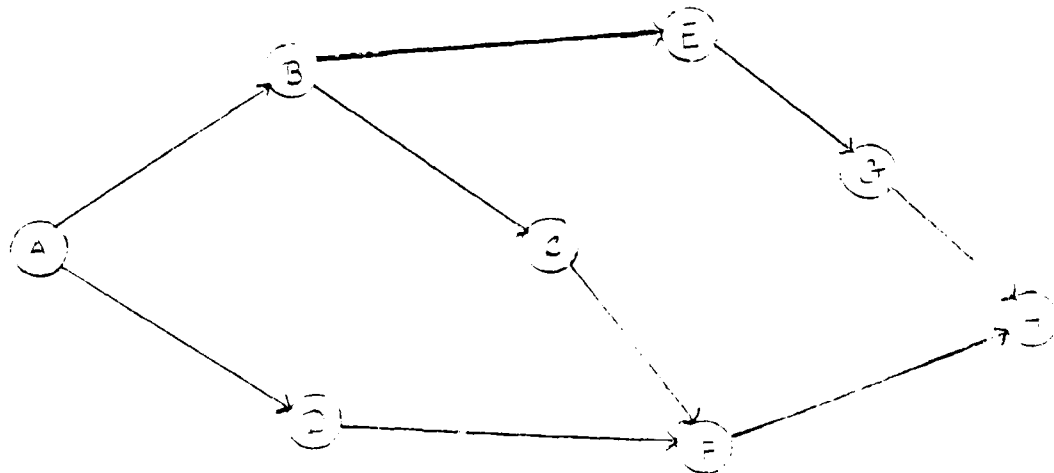
## Work Breakdown Structure

A Work Breakdown Structure (WBS) displays and defines the product(s) to be developed or produced and relates the element of work to be accomplished to each other and to the end product. (Source Military Standard 881A.) The objective of the WBS is to divide the total program/project or product into smaller assignable work units. The result is a tree-like diagram (model of the project) of successive levels of project work units as shown in the figure below.



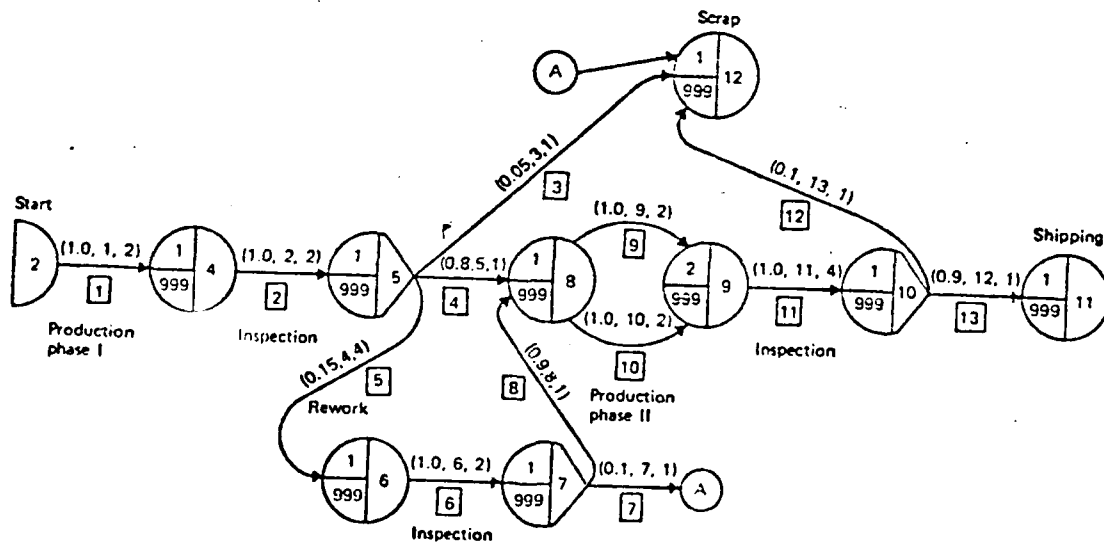
### Activity Networks

Activity Networks can be thought of as modified project scheduling charts because in addition to graphically representing activities and events over a specified period of time, Activity Networks identify all sequences of activities. The network has an arrow for each project activity. The analysis of Activity Networks focuses on the most time-consuming path (the critical path) through the network as a basis of planning and controlling a project. An example of an Activity Network shown in the figure below, Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) are probably the best known Activity Networks.



### Generalized Activity Network

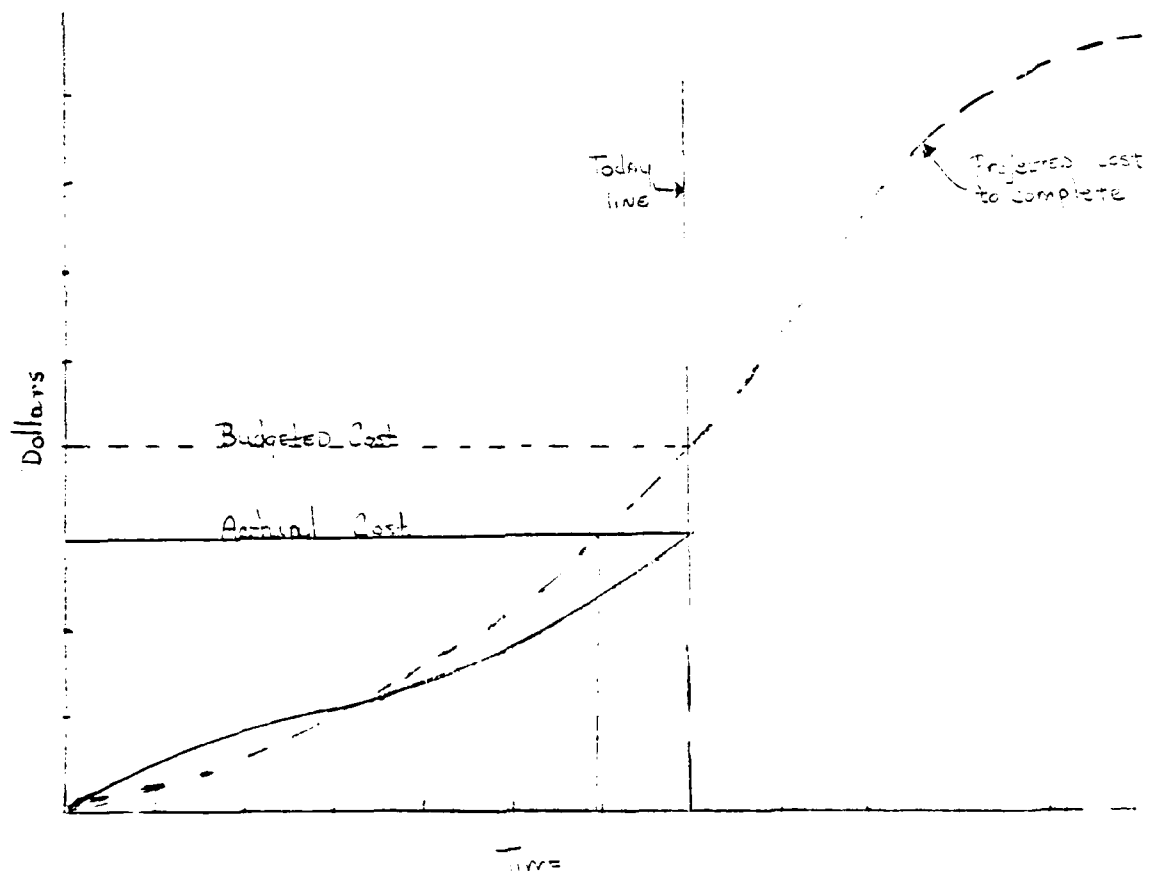
In this study all network techniques more complex than PERT/CPM in their basic forms will be considered a Generalized Activity Network technique. Generalized Activity Network techniques allow (i) both deterministic and stochastic branching, (ii) looping, (iii) multiple sink nodes, and (iv) other complications not allowed in PERT/CPM networks. Events or nodes are considered to have input and output sides which specify how they interrelate to incoming and outgoing actions (branches). The following techniques are examples of General Activity Networks: Graphical Evaluation and Review Techniques Simulation (GERTS), Venture Evaluation and Review Technique (VERT), Q-GERT, and GERT. An example of GERT, a Generalized Activity Network, is shown in the figure below.



GERT network of production example

### Cost and Schedule Variance Analysis

Cost and Schedule Variance Analysis is a technique of planning and controlling by comparing planned resource usage and achievements with actual expenditures and accomplishments. When the planned expenditures are plotted against time as shown in the figure below, any deviations from the budget or schedule are readily recognized. Cost and Schedule Variance Analysis is sometimes used to supplement other techniques since it integrates the cost parameter with the planning and controlling of the performance and schedule parameters for R&D projects.



Technique Familiarity Scale (Scale-1)

- (1) I have never heard of it before.
- (2) I have heard of it before, but do not know any details about it.
- (3) I have a little knowledge of it (i.e., I have read or talked to others about it).
- (4) I am moderately knowledgeable about it.
- (5) I consider myself very knowledgeable about this technique.
- (6) I consider myself an expert on this technique.

Technique Usefulness Scale (Scale-2)

- (1) Is of no use.
- (2) Is of some use, but not as useful as other techniques.
- (3) About as useful as other techniques.
- (4) Is more useful than other techniques.
- (5) Is a very useful technique, far more so than others.
- (6) Is the best technique.

Techniques Being Investigated

- (1) Participative Objective Setting
- (2) Work Breakdown Structures
- (3) Project Scheduling Charts
- (4) Activity Networks
- (5) Generalized Activity Networks
- (6) Cost and Schedule Variance Analysis

Name:

Organization:

Grade:

Job Title:

1. How long have you held your present job?
2. What is the approximate cost of the program/project that you are working on? (Total RDT&E costs)
3. What is the approximate number of people here at WPAFB who work on this program/project?
4. Which of the following best describes the activities of your organization?
  - a. Research
  - b. Exploratory Development
  - c. Advanced Development
  - d. Engineering Development
  - e. Other \_\_\_\_\_ (specify)
5. How long has your program/project been in operation?
6. How familiar are you with Participative Objective Setting Techniques? (Use Scale-1)    1    2    3    4    5    6
7. Have you had any training in using the above technique?  
Was this training
  - a. college
  - b. short course
  - c. OJT
  - d. PME (e.g. SOS, ACSC)
8. Is Participative Objective Setting used to plan your project/program activities?
  - a. Never
  - b. Occasionally
  - c. Often
  - d. Always
9. Is Participative Objective Setting used to control your program/project activities?
  - a. Never
  - b. Occasionally
  - c. Often
  - d. Always

10. How useful do you think is the Participative Objective Setting Technique in planning your program/project activities? (Use Scale-2) 1 2 3 4 5 6
11. How useful do you think is the Participative Objective Setting Technique in controlling your project/program activities? (Use Scale-2) 1 2 3 4 5 6
12. How familiar are you with Project Scheduling Charts? (Use Scale-1) 1 2 3 4 5 6
13. Have you had any training in using the above technique?  
Was this training
- a. college
  - b. short course
  - c. OJT
  - d. PME (e.g. SOS, ACSC)
14. Are Project Scheduling Charts used to plan your program/project activities?
- a. Never
  - b. Occasionally
  - c. Often
  - d. Always
15. Are Project Scheduling Charts used to control your program/project activities?
- a. Never
  - b. Occasionally
  - c. Often
  - d. Always
16. How useful do you think are Project Scheduling Charts in planning your program/project activities? (Use Scale-2) 1 2 3 4 5 6
17. How useful do you think are Project Scheduling Charts in controlling your program/project activities? (Use Scale-2) 1 2 3 4 5 6
18. How familiar are you with Work Breakdown Structure? (Use Scale-1) 1 2 3 4 5 6
19. Have you had any training in using the above technique?  
Was this training
- a. college
  - b. short course
  - c. OJT
  - d. PME (e.g. SOS, ACSC)



20. Are Work Breakdown Structures used to plan your project/  
program activities?  
a. Never  
b. Occasionally  
c. Often  
d. Always
21. Are Work Breakdown Structures used to control your program/  
project activities?  
a. Never  
b. Occasionally  
c. Often  
d. Always
22. How useful do you think are Work Breakdown Structures in  
planning your program/project activities?  
(Use Scale-2) 1 2 3 4 5 6
23. How useful do you think are Work Breakdown Structures in  
controlling your program/project activities?  
(Use Scale-2) 1 2 3 4 5 6
24. How familiar are you with Activity Networks?  
(Use Scale-1) 1 2 3 4 5 6
25. Have you had any training in using the above technique?  
Was this training  
a. college  
b. short course  
c. OJT  
d. PME (e.g. SOS, ACSC)
26. Are Activity Networks used to plan your program/project  
activities?  
a. Never  
b. Occasionally  
c. Often  
d. Always
27. Are Activity Networks used to control your program/project  
activities?  
a. Never  
b. Occasionally  
c. Often  
d. Always
28. How useful do you think are Activity Networks in planning  
your program/project activities?  
(Use Scale-2) 1 2 3 4 5 6

39. Is Cost and Schedule Variance Analysis used to control your program/project activities?
- a. Never
  - b. Occasionally
  - c. Often
  - d. Always
40. How useful do you think is Cost and Schedule Variance Analysis in planning your program/project activities?  
(Use Scale-2)      1      2      3      4      5      6
41. How useful do you think is Cost and Schedule Variance Analysis in controlling your program/project activities?  
(Use Scale-2)      1      2      3      4      5      6
42. Do you have computer support for such techniques available to you for planning and controlling purposes?
43. What is (are) the primary technique(s) used on your program/project for planning?
44. What is (are) the primary technique(s) used on your program/project for controlling?
45. What other technique(s) do you use?
46. What do you think should be the primary technique(s) for planning your program/project activities?
47. What do you think should be the primary technique(s) for controlling your program/project activities?
48. Do you know anyone else who uses any of these techniques?

29. How useful do you think are Activity Networks in controlling your program/project activities?  
(Use Scale-2)      1      2      3      4      5      6
30. How familiar are you with Generalized Activity Networks?  
(Use Scale-1)      1      2      3      4      5      6
31. Have you had any training in using the above technique?  
Was this training
- a. college
  - b. short course
  - c. OJT
  - d. PME (e.g. SOS, ACSC)
32. Are Generalized Activity Networks used to plan your program/project activities?
- a. Never
  - b. Occasionally
  - c. Often
  - d. Always
33. Are Generalized Activity Networks used to control your program/project activities?
- a. Never
  - b. Occasionally
  - c. Often
  - d. Always
34. How useful do you think are Generalized Activity Networks in planning your program/project activities?  
(Use Scale-2)      1      2      3      4      5      6
35. How useful do you think are Generalized Activity Networks in controlling your program/project activities?  
(Use Scale-2)      1      2      3      4      5      6
36. How familiar are you with Cost and Schedule Variance Analysis?  
(Use Scale-1)      1      2      3      4      5      6
37. Have you had any training in using the above technique?  
Was this training
- a. college
  - b. short course
  - c. OJT
  - d. PME (e.g. SOS, ACSC)
38. Is Cost and Schedule Variance Analysis used to plan your project/program activities?
- a. Never
  - b. Occasionally
  - c. Often
  - d. Always

Demographic

Name: \_\_\_\_\_

Organization: \_\_\_\_\_

Grade: \_\_\_\_\_

Job Title: \_\_\_\_\_

1. \_\_\_\_\_

2. \_\_\_\_\_

3. \_\_\_\_\_

4. \_\_\_\_\_

5. \_\_\_\_\_

6. \_\_\_\_\_

Summary

42. \_\_\_\_\_

43. \_\_\_\_\_

44. \_\_\_\_\_

45. \_\_\_\_\_

\_\_\_\_\_

46. \_\_\_\_\_

47. \_\_\_\_\_

48. \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

POST					PSC					WBS					AN					GAN					CSVA				

SELECTED BIBLIOGRAPHY

# REFERENCES CITED

1. Air Force Systems Command. Cost Management for Small Projects. AFSC Pamphlet 173-3. Andrews AFB, MD: Air Force System Command, October 1, 1975.
2. Albanese, Robert. Managing toward Accountability for Performance. Homewood, Illinois: Richard D. Irwin, Inc., 1978, pp. 82-87.
3. Argenti, John. Management Techniques: A Practical Guide. EPINBURCH: George Allen and Union LTD, 1969.
4. Baumgartner, John S. Project Management. Homewood, Illinois: Richard D. Irwin, Inc., 1963, pp. 38.
5. Beattie, C. J. and R. D. Reader. Quantitative Management in R & D. Fakenham, Great Britian: Cox and Wyman LTD, 1971, pp. 251.
6. Bellas, C. J. and A. C. Samli. "Improving New Product Planning with GERT Simulation," California Management Review. XV, No. 4 (Summer 1973), pp. 14-21.
7. Brown, Harold. "Management of Defense R&D," Science, Technology and Management. New York: McGraw-Hill Book Company, Inc., 1963, pp. 330-332.
8. Budnick, Frank S., Richard Mojena, and Thomas Vollman. Principles of Operation Research for Management. Homewood, Illinois: Richard D. Irwin, Inc., 1977, pp. 534.
9. Chase, Richard B. and Nicholas J. Aquilno. Production and Operation Management. Homewood, Illinois: Richard D. Irwin, Inc., 1977, pp. 547-53.
10. Clayton, E. R. and L. J. Moore. "GERT vs PERT," Journal of System Management. Vol. 23, No. 2 (February 1972), pp. 11-19.
11. Department of Defense. "Work Breakdown Structure for Defense Materiel Items," Military Standard 881-A. April 25, 1975, pp. 1,2,7.

12. Department of Defense Directive 5010.20. "Work Breakdown Structure," Washington, D. C.: U. S. Government Printing Office, July 31, 1968, pp. 2.
13. Department of the Air Force. Air Force Research and Development. AFR 80-1. Washington, D. C.: U. S. Government Printing Office, June 15, 1979, pp. 2.
14. Department of the Army. Improving the Methods of Planning and Coordinating Scientific Research in Industries. Charlottesville, Virginia: U. S. Army Foreign Science and Technology Center, February 1977.
15. Digman, L. A. and Gary I. Green. "A Framework for Evaluating Network Planning and Control Techniques," Research Management. Vol. 22, January 1981, pp. 10-17.
16. Elmaghraby, Salah. Activity Networks: Project Planning and Control by Networks. New York: John Wiley & Son, Inc., 1967, pp. 323-57.
17. Evans, George C. Supervising R&D Personnel. American Management Association, 1969, pp. 21.
18. Ferguson, Joseph C. "Applying the Key Work Objectives Approach to R&D," Research Management. Vol. 19, July 1976, pp. 33.
19. Francis, Philip H. Principles of R&D Management. New York: AMACOM, 1977, pp. 105-111.
20. Fulton, Darrel N. and Donald D. Wright. DoD Resource Management System: Systems for Management of Capital Acquisition. Graduate Education Division School of Systems & Logistic, AFIT, Wright-Patterson AFB, OH, 1978, pp. 33-36.
21. Howard, George W. Common Sense in R&D Management. New York: Vantage Press, 1955, pp. 5, 14, 50.
22. Jackson, Thomas and Jack Spurlock. R&D Management. Homewood, Illinois: Dow-Jones-Irwin, Inc., 1966, pp. 145.
23. Karger, Delmar W. and Robert G. Murdick. Managing, Engineering and Research. New York: Industrial Press, Inc., 1969.

24. Kast, Fremont E. and James L. Rosenweig. Science, Technology, and Management. New York: McGraw-Hill Book Company, Inc., 1963, pp. 150.
25. Kerzner, Harold. Project Management a System Approach to Planning, Scheduling, and Controlling. New York: Van Nostrand Reinhold Company, 1979.
26. Klementowski, Lawrence. PERT/CPM and Supplementary Analytical Techniques. Wright-Patterson AFB, OH, AFIT, 1978.
27. Mann, Greg A. "VERT: A Risk Analysis Tool for Program Management," Defense Management Journal. May-June, 1979, pp. 32-36.
28. Martin, Charles C. Project Management. New York: AMACOM, 1978, p. 182.
29. Moore, Laurence J. and Edward R. Clayton. GERT Modeling and Simulation: Fundamentals and Application. New York: Petrocelli/Charter, 1976, pp. 53-61.
30. Murphy, Sheldon R. "Five Ways to Improve R&D Efficiency," Research Management. Vol. 22, January 1981, pp. 8, 9.
31. O'Brien, James J. Scheduling Handbook. New York: McGraw-Hill Book Company, 1974, pp. 299-300.
32. Pritsker, A. Alan B. Modeling and Analysis Using Q-GERT Networks. New York: John Wiley & Sons, Inc., 1979.
33. Roman, Daniel D. R&D Management: The Economic and Administration of Technology. New York: Appleton-Century-Crafts, 1968, pp. 236.
34. Tauss, Kurt H. "A Pragmatic Approach to Evaluating R&D Programs," Research Management. Vol. 18, September 1975, pp. 13-15.
35. Thomason, George F. The Management of Research and Development. London: BT Batsford, 1970, pp. 236, 230.



36. Twiss, Brian C. Managing Technological Innovation. London: Longman Group Limited, 1974, pp. 11.
37. Villers, Raymond. R&D Planning and Control. New York: Rautenstrauch and Villers, Inc., 1964, pp. 4.
38. Whitehouse, Gary. System Analysis and Design Using Network Techniques. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1973.

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